OUTLOOK AND RESEARCH POSSIBILITIES FOR BITUMINOUS COAL

By Bureau of Mines in Cooperation
with Bituminous Coal Research, Inc.

Information Circular 7754

UNITED STATES DEPARTMENT OF THE INTERIOR
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CONTENTS

	Page
Introduction	1
Summary	3
Survey of bituminous-coal research, 1955	3
Total energy requirements of the future	7
Coal's decline	9
Coal's potentials	9
Coal reserves	9
Location	9
Special purpose coals	12
Research possibilities	12
Production and distribution	12
Mining	12
Underground mining	12
Auger mining	14
Strip mining	14
Thickness of seams	14
Number and size of mines	15
Productivity	15
Capacity	15
Technological problems and research possibilities	15
Underground gasification	19
Technological problems and research possibilities	19
Preparation	20
Mechanical cleaning	20
Mechanical crushing	21
Technological problems and research possibilities	21
Transportation and storage	25
Transportation	25
Freight rates	26
Railroad-car supply	26

Information Circular 7754

CONTENTS (Con.)

Page

- Storage 26
  - Technological problems and research possibilities 26
- Coal markets 29
  - Power generation 31
    - Public utilities 31
      - Potential future energy demand 31
      - Technological problems and research possibilities 31
  - Motive power 34
      - Railroads 34
      - Ships 35
    - Potential future energy demand 35
    - Technological problems and research possibilities 35
  - Other industrial 36
    - Potential future energy demand 36
    - Technological problems and research possibilities 36
  - Residential and commercial heating 41
    - Potential future energy demand 41
    - Technological problems and research possibilities 41
  - Coke and coal chemicals 42
    - Potential future energy demand 43
    - Technological problems and research possibilities 43
  - Gasification and uses of synthesis gas 46
    - Potential future energy demand 47
    - Technological problems and research possibilities 48
  - Coal hydrogenation 49
    - Technological problems and research possibilities 50
- Physical and chemical properties of coal 50
    - Technological problems and research possibilities 51

TABLES

1. Summary data on coal research, 1955 3
2. Bituminous-coal research, 1955 4
3. Sources of funds for bituminous-coal research 6
4. Estimated total energy requirements, by consumer groups, 1955-80, in trillion British thermal units and bituminous-coal equivalent 8
5. Potential contribution of bituminous coal and lignite to estimated future energy requirements on the basis of varying rates of coal's participation in the total energy market 8
6. Remaining coal reserves of the United States, January 1, 1953 9

TABLES (Con.)

Pages

7. Coal reserves of the United States, January 1, 1953, by States (million short tons) 11
8. Production of bituminous coal and lignite in the United States, by method of mining, 1925-55 (thousand net tons) 13
9. Percentage of total production of underground mines in the United States, 1950, by thickness of seams mined ... 14
10. Number of bituminous-coal and lignite mines in the United States and potential productive capacity at 225 and 280 days' work, 1925-53 16
11. Consumption of bituminous coal and lignite, by consumer class, with retail deliveries in the United States, 1925-55, in thousand net tons 32
12. Consumption of bituminous coal in the manufacture of oven and beehive coke for 5-year periods, 1925-54, in net tons 43

ILLUSTRATIONS

Fig.

1. Percentage of total British thermal units equivalent contributed by the several sources of energy in the United States, counting waterpower at the prevailing fuel equivalent of central stations in each year, 1899-1953. 10
2. Percentage of total production of bituminous coal and lignite crushed at mines in the United States, 1940 and 1944-53 22
3. Percentage of total production of bituminous coal and lignite, 1933-53, by method of shipment from mine, and used at mine 27
4. Trends of stocks of bituminous coal and lignite in the United States, 1944-53 28
5. Consumption of bituminous coal and lignite, by consumer class, with retail-dealer deliveries in the United States, 1944-53 30

INTRODUCTION

An accelerated and coordinated program of coal research is believed by many to be a necessary step in assuring coal's proper position in the expanding energy market. The President's Advisory Committee on Energy Supplies and Resources Policy, for example, made the following recommendation:

> We recognize that coal is a great national asset and endorse a cooperative study to determine what research and development could be undertaken. The coal industry and both Federal and State Governments should participate in this study and its costs.

Representatives of the coal industry have agreed that such a study should be initiated. Accordingly, Felix E. Wormser, Assistant Secretary - Mineral Resources, United States Department of the Interior, requested the Bureau of Mines and Bituminous Coal Research, Inc., to conduct a survey of current research on bituminous coal. In addition to this survey, studies were made to determine research projects that would be of value to the coal industry.

The survey covers research on bituminous coal in the United States in some detail. An attempt was also made to survey foreign research; but, because of the time limitation, only general information currently available was used. Because the economy of most industrialized foreign countries is tied directly to coal, they are ahead of the United States in many coal research undertakings. More details on foreign research should be available to insure an optimum expanded research program for coal. In addition to research and development work of the coal industry, that of associated industries and coal consumers is covered. Not included, however, are secondary studies, such as research on the economics of power transmission, electric power equipment, etc. Nontechnical industry problems, routine analyses, service, trouble shooting, acceptance testing, and most work performed in production departments are also excluded. The United States coal-research survey covered 50 industrial companies, 10 State institutions, 18 academic institutions, 8 research institutes, and pertinent departments of the Federal Government.

Concern over the sources of supply needed to satisfy the growing energy market has resulted in a number of estimates; even the most conservative indicate a tremendous increase in total demand. A recent report of the Joint Committee for Atomic Energy indicates that atomic energy for the production of electric power would be a comparatively small factor by 1975 and would only supplement mineral fuels. A predicted decrease of reserves of the more convenient fluid fuels - natural gas and petroleum - also indicates that new markets may be opened to coal in the future.

A review was made of the economic position of the coal industry over the past several decades, and the competitive forces responsible for coal's position are summarized. In connection with this phase of the report, a projection of the energy demand, market by market, was considered necessary, because the type of market determines the quality and type of coal needed and its availability in various locations. These estimates were based upon projections of past trends in the respective consumer categories, adjusted for such factors as Bureau of Census estimates of population growth and forecasts of Gross National Product, estimates of future power requirements by the Federal Power Commission, and estimates of requirements by the steel industry. Although the future of coal appears to be much brighter than it has been for many years, the amount of the energy market that coal will get will be determined by the aggressiveness of the coal industry to obtain these markets. Intensive research now will insure the availability of technology in the future to adapt coal to the changing demands of its consumers and thus assure the Nation an adequate energy supply.

In the past 10 years there has been a growing awareness throughout the world of problems associated with air and stream pollution. Although these have been of concern to the coal industry for many years, the increased interest in them by legislative bodies requires that a solution be found for the more pressing problems, if coal is to achieve the predicted markets. Therefore, recommendations for research have been included in this report concerning abatement of air and stream pollution.

In the report 209 research possibilities are listed. Each of these research possibilities must be examined in detail to determine the economic and technologic feasibility before undertaking a research project. Many of them appear to be similar to past studies; and, in fact, much work is underway at present on phases of many of these research possibilities. In many cases, however, insufficient time, effort, or money was spent on problems. Furthermore, as the overall economics changes, processes that appeared uneconomical earlier may be feasible today. New scientific developments, apparatus, and new approaches can now be applied to older problems; new processes to meet the new demands of consuming industries such as chemicals, gas, and liquid fuels may offer vast new markets. Increased demand for chemical raw materials and for more convenient (gaseous and liquid) sources of energy create an entirely new set of research objectives.

In listing these broad research possibilities, it was felt that each merited some further consideration. No suggestion was made as to whether industry, universities, or State or Federal organizations would be best equipped to work on a given problem. No attempt was made to give priority to the research possibilities.

No separate recommendations have been made concerning the scientific literature on coal and related subjects. Bituminous Coal Research, Inc., and the Bureau of Mines agree with the suggestions of several respondants to the coal survey that a great need exists for an American journal that will bring together contributions on coal science. Furthermore, a need exists for a systematic compilation of comprehensive physical and chemical data on coal and its primary products. Moreover, although we recognize the need for a number of technical-economics studies to properly evaluate some of these research possibilities, recommendations concerning them were not included in this report.

Bituminous Coal Research, Inc., assisted in the research survey and provided much of the material, time, and effort for the technical and economic review. The cooperation of this organization and of others that contributed to the survey is gratefully acknowledged and very much appreciated.

SUMMARY

A survey of 1955 coal-research projects revealed the data shown in table 1.

TABLE 1. - Summary data on coal research, 1955

	Expenditures		Professional manpower	
	Dollars	Percent	Number	Percent
Coal resources	1,478,600	8.5	187	19.8
Mining	3,038,700	17.5	140	14.8
Preparation	606,400	3.4	45	4.8
Storage and transportation	97,900	.6	5	.5
Combustion	1,121,800	6.4	42	4.5
Coke and coal chemicals	5,435,400	31.3	273	28.9
Gasification of coal	2,517,900	14.5	91	9.7
Coal hydrogenation	2,080,100	12.0	93	9.8
Physical and chemical properties	1,005,600	5.8	68	7.2
Total	17,382,400	100.0	944	100.0

Although the total effort is impressive, it is not large when compared with research and development expenditures in other industries. Moreover, much of the reported work is on the development and improvement of equipment. In addition, there is some imbalance in the funds and manpower applied to different phases of coal research.

The Nation's projected total energy requirement for 1975, in terms of bituminous-coal equivalent, is 2,530 million tons. Coal now supplies about 30 percent of the total energy demand. If this percentage is maintained in 1975, approximately 759 million tons of coal will be required. With the relatively limited reserves of liquid and gaseous fuels and after allowance for a considerable expansion in availability of atomic energy, coal's share of the total energy demand may be expected to increase over its present 30 percent. For each 5-percent increase of total demand, approximately 120 million more tons of coal would be required. However, even at the lower limit of projected demand for 1975, the present capacity of mines is insufficient, and additional mines will have to be opened.

Although the projected energy demand indicates a favorable position for coal in the future, competition among the fuels will continue and will be complicated further by availability of new sources of energy, such as oil shale, atomic energy, and possibly solar energy. We have tried to point out in this report the technologic problems that must be solved if coal is to be assured its proper share of total energy demand. Two hundred and nine research possibilities of different degrees of urgency are made on all phases of technology, from mining to possible new markets. Much of this program must be begun at once if the technology is to be available when needed.

SURVEY OF BITUMINOUS-COAL RESEARCH, 1955

The main results of the joint Bureau of Mines - Bituminous Coal Research, Inc., survey of current coal research are summarized in tables 2 and 3.

TABLE 2. - Bituminous-coal research, 1955

Type of study	No. of projs.	Work done by					Annual amt., $	% of total funds	Prof. men/ year	% of total manpower	Approach to problems				
		Fed. Govt.	State Govt.	Univ.	Res. inst.	Ind.					Lab.	Pilot plant	Proto. equip.	Field or commercial study	Statistics
Coal Resources															
Exploration, mapping, trace minerals such as uranium and germanium.	-	x	x	x	x	-	1,117,700	6.4	139.5	14.8	x	-	-	x	x
Petrography, geology, and other earth sciences as applied to resources.	-	x	x	-	-	-	360,900	2.1	47.0	5.0	x	-	-	-	-
Subtotals	18	-	-	-	-	-	1,478,600	8.5	186.5	19.8	-	-	-	-	-
Similar work in France, Germany, England, Australia, Canada, India, South Africa, and Russia.															
Physical and Chemical Properties															
Sampling, analysis, structure, reactivity.	25	x	x	x	x	-	1,005,600	5.8	68.4	7.2	x	x	-	x	x
Similar work in France, England, Australia, Canada, India, South Africa, Netherlands, and Japan. England and Netherlands appear to have much stronger programs than the United States.															
Mining							(mostly equipment manufactured)								
Continuous mining and associated problems.	-	-	-	x	x	x	1,629,100	9.4	81.3	8.6	x	-	x	x	-
Roof control (faults, pillars, bolts, temporary supports).	-	-	-	x	x	x	173,100	1.0	11.5	1.2	x	-	x	x	-
Transportation and communication.	-	-	-	-	x	x	819,700	4.7	16.0	1.7	x	-	x	x	-
Augers, drills, safety equipment, acid drainage.	-	x	-	-	x	x	416,800	2.4	31.0	3.3	x	-	x	x	x
Subtotals	25	-	-	-	-	-	3,038,700	17.5	139.8	14.8	-	-	-	-	-
Similar work in France, Germany, England, Australia, Canada, Russia. In addition, England is working on tunneling and Russia on hydraulic mining.															
Preparation															
Fine-coal cleaning and recovery (equipment and methods).	-	x	-	x	-	x	227,400	1.3	16.0	1.7	x	x	x	x	-
Coarse-coal cleaning (equipment and methods).	-	x	-	-	-	-	40,000	.2	2.5	.3	-	x	-	x	-
Fine-coal drying and dewatering (equipment and methods).	-	x	-	x	-	x	216,000	1.2	14.5	1.5	x	x	x	x	-
Crushing (preparation and storage of lignite).	-	x	-	-	-	-	23,500	.1	2.0	.2	x	x	-	x	-
Washing characteristics of coals.	-	x	-	x	-	x	86,500	.5	8.7	.9	x	x	-	-	-
Miscellaneous (no details to preserve anonymity).	-	-	-	x	-	x	13,000	.1	1.5	.2	x	-	-	x	-
Subtotals	20	-	-	-	-	-	606,400	3.4	45.2	4.8	-	-	-	-	-
Similar work in France, Germany, England, Canada, India, South Africa, Japan, and Russia. In addition, France, England, Canada, and India work on briquetting, Japan on electrostatic cleaning.															
Storage and Transportation															
Hydraulic transport, storage, handling, equipment (see also under Preparation and Combustion; the latter includes rail transport equipment).	4	x	-	-	x	x	97,900	.6	4.5	.5	x	x	-	x	x
Similar work in Australia, India, Germany, and Russia. The last two are also working on hydraulic transportation.															

TABLE 2. - Bituminous-coal research, 1955 - Con.

Type of study	No. of projs.	Work done by: Fed. Govt.	State Govt	Univ.	Res. inst.	Ind.	Annual amt., $	% of total funds	Prof. men/year	% of total manpower	Approach to problems: Lab.	Pilot plant	Proto. equip.	Field or commercial study	Statistics
Combustion															
Combustion characteristics (low-grade fuel, powdered coal) and boiler-water research.	-	x	-	-	-	x	181,000	1.0	15.6	1.7	x	x	x	-	x
Equipment for preparation and combustion (home, industrial and agricultural).	-	x	-	x	x	x	770,300	4.4	15.0	1.6	x	x	x	x	x
Byproducts (recovery and use of ash and sulfur) and pollution control.	-	x	-	x	x	-	170,500	1.0	11.2	1.2	x	x	x	x	x
Subtotals	30	-	-	-	-	-	1,121,800	6.4	41.8	4.5	-	-	-	-	-

Similar work in France, Germany, England, Australia, Canada, India, South Africa, Japan, Austria. The International Flame Research Committee (British, Netherlands, French, Swedish) studies coal burning, especially pulverized coal. In addition, England is working on combustion of smoke, delayed combustion, and smokeless fuel.

Type of study	No. of projs.	Work done by: Fed. Govt.	State Govt	Univ.	Res. inst.	Ind.	Annual amt., $	% of total funds	Prof. men/year	% of total manpower	Approach to problems: Lab.	Pilot plant	Proto. equip.	Field or commercial study	Statistics
Coke and Coal Chemicals (except Hydrogenation and Gasification)															
Carbonization characteristics, oven design, and testing (including sulfur, petrography, banded ingredients, blending, swelling, plasticity, strength, rate of carbonization, etc.).	-	x	x	x	x	x	744,700	4.3	45.4	4.8	x	x	x	x	x
High-temperature carbonization and products (quality and quantity of coke, tar, and gas; metallurgy; chemicals).	-	-	-	x	x	x	2,571,300	14.8	127.5	13.5	x	x	x	x	-
Low-temperature carbonization and products (processes, solid fuel, tar and gas chemicals).	-	x	-	x	x	x	1,897,100	10.9	81.5	8.6	x	x	x	x	-
Special products (industrial carbons, charcoals, fertilizer, chemicals directly from coal).	-	x	-	x	x	x	222,300	1.3	19.0	2.0	x	x	x	x	-
Subtotals	57	-	-	-	-	-	5,435,400	31.3	273.4	28.9	-	-	-	-	-

Similar work in France, Germany, England, Australia, Canada, India, South Africa, Netherlands, Austria, Japan, and Russia. France appears to be carrying on the most intensive laboratory research. India is studying ion exchange compounds and desiccants from coal, Netherlands carbide from coke.

Type of study	No. of projs.	Work done by: Fed. Govt.	State Govt	Univ.	Res. inst.	Ind.	Annual amt., $	% of total funds	Prof. men/year	% of total manpower	Approach to problems: Lab.	Pilot plant	Proto. equip.	Field or commercial study	Statistics
Gasification of Coal															
Gasification, including underground gasification (lump and powdered fuel, synthesis gas, methane) and purification of gas (removal of dust etc.).	-	x	-	x	x	x	1,977,700	11.4	65.9	7.0	x	x	x	x	x
Uses of gas (fuel cell, Fischer-Tropsch and related processes for liquid fuels, waxes, chemicals, etc. Does not include conversion of natural gas to these products).	-	x	-	x	-	x	540,200	3.1	25.5	2.7	x	x	-	-	-
Subtotals	24	-	-	-	-	-	2,517,900	14.5	91.4	9.7	-	-	-	-	-

Similar work in France, Germany, England, Australia, India, South Africa, Netherlands, Austria, Japan, Russia. In addition, England is studying milled peat, and England and Russia are working on underground gasification.

Type of study	No. of projs.	Work done by: Fed. Govt.	State Govt	Univ.	Res. inst.	Ind.	Annual amt., $	% of total funds	Prof. men/year	% of total manpower	Approach to problems: Lab.	Pilot plant	Proto. equip.	Field or commercial study	Statistics
Coal Hydrogenation															
Chemicals, liquid fuels, methane.	5	x	-	-	x	x	2,080,100	12.0	92.6	9.8	x	x	x	x	x
TOTALS	208	-	-	-	-	-	17,382,400	100.0	943.6	100.0	-	-	-	-	-

TABLE 3. - Sources of funds for bituminous-coal research[1/]

Federal	$ 4,863,737
State	579,727
Commercial coal	2,452,284
Captive coal	1,206,888
Equipment manufacturers	3,220,810
Other industrial	4,954,954
University and unidentified funds	104,000
Total	$17,382,400

[1/] When companies were known to be engaged in several functions (for example, a company that makes equipment, processes coal, and sells coal) and where several projects were reported by such a company, an attempt was made to distribute the amounts to the appropriate lines in the table.

The following limitations apply to table 2: A few companies preferred to give only totals, and an arbitrary allocation to certain functions (those believed to be most important in the companies' programs) was necessary in these instances. Overhead and administrative charges were usually included in the individual reports; however, because of the great variation in overhead, no attempt was made to adjust the few reported net figures to gross figures. A small error enters into the manpower figures because, in university research, students were sometimes counted as full-time and sometimes as part-time, and sometimes they were not included as professional employees. Professional employees were defined as persons holding degrees in science or technology or having equivalent experience and duties. The expenditures generally cover 1955, although in a few instances 1954 or projected 1956 figures were the only ones available.

Table 3 indicates the sources of funds for coal research and shows that approximately equal shares are contributed by coal producers, equipment manufacturers, coal consumers, and the Federal Government.

Despite the many limitations of the survey, it reveals the scope of coal-research activities, particularly in the United States, in semidetail not heretofore available. Total annual research and development expenditures for coal are shown to exceed $17 million. This is, of course, a minimum amount, because some organizations may have been overlooked and eight of those contacted did not reply. In only one instance, where the average annual expenditure of a company on research and development was known, was this amount entered in the table, with an estimate of the manpower, in lieu of a direct reply. By way of comparison, 1953 research expenditures (according to the National Science Foundation) by the petroleum industry were $145.9 million; textile industries, $28.0 million; rubber products, $53.6 million; and chemical industry, $361.1 million.

Of the total amount in table 2, almost one-third was spent on coke and coal chemicals. This category also employed the largest number of scientists and engineers - 273 professional employees of a total of 944 covered in the survey. Next in importance, based on expenditures, is mining, principally because of the high cost of developing large mining equipment. The second largest function, based on manpower, is the exploration and study of new coal resources. Although combustion constitutes the greatest end use of coal, it is in sixth place (based on dollars) and in eighth place (based on professional manpower). Coal gasification and hydrogenation are in third and fourth places, in terms of expenditures. By far the smallest effort, about 1/2 percent on both bases, goes into storage and transportation.

TOTAL ENERGY REQUIREMENTS OF THE FUTURE

The unprecedented and continuing growth of our population, the tremendously accelerating demand for electric power, and the heavy expansion of our industrial economy indicate that demands for energy will reach phenomenal proportions within the next 25 years. Although there are some differences in the estimates of various experts as to the magnitude and timing of successive new peaks in total energy demand, these estimates fall within a range that indicates an increase of about 25,000 to 30,000 trillion B.t.u. over the present energy demand in the next 20 years, or approaching a two-thirds increase.

The principal interests with respect to coal in these forecasts are (1) the extent to which it will participate in the increased energy demand and (2) when the increasing demand will begin to manifest itself in terms of substantial and sustained increases in coal production and utilization.

The answers to both questions lie primarily in the extent to which the coal industry will be prepared to assume the greatest share of the expanded energy market, as distinguished from having to accept the residual demand that cannot be supplied by other energy sources.

Each major facet of coal technology - production, transportation, and utilization - will require early planning and action on an unprecedented scale if the objective is to be met. Coal producers, transporters, and users alike will have to participate if the Nation is to get the greatest value from one of its largest natural sources of energy.

To appraise future energy demands with reference to coal it has been necessary to analyze the potential demands on the basis of principle energy markets rather than to estimate future energy demands on a total basis.

Table 4 shows the grand totals for the years covered in this estimate, based on the potential demand in the major consumer classifications. The latter are covered in more detail in the discussion of the respective market groups under Coal Markets on page 29. Although this total differs somewhat from those given by other sources, such differences are normal for long-range forecasting where so many complex variables are involved. Even within the range of differences, total energy requirements are expected to increase 1 billion tons or more in bituminous coal equivalent in the next 25 years over the current 1-1/2 billion tons (in bituminous coal equivalent). Some of this demand will be supplied by imported energy. If the trend of energy imported for the past 15 years is projected, approximately 17 percent of the 1975 energy demand would be supplied by imports.

To the extent that the predominantly coal based economies of Europe continue to expand appreciably beyond the abilities of their native coal industries to supply the demand, and insofar as the extra demand is not taken over by competitive fuels, it is expected that United States coal exports will continue correspondingly. On this basis, plus the fact that the European market for United States coal now is largely on a free dollar basis, it is anticipated that, for some time ahead, there will be an appreciable overseas export market for United States coal, although the degree of stability is open to conjecture.

TABLE 4. - Estimated total energy requirements, by consumer groups, 1955-80, in trillion British thermal units and bituminous-coal equivalent[1]

Year	Electric power utilities	Motive power	Coke and coal chemicals	Other industries	Residential and commercial	Exports	Grand total trillion B.t.u.[2]	Bituminous-coal equivalent[2] (million tons)
1955--	5,265	9,365	2,805	13,300	8,265	2,200	41,200	1,573
1960--	7,000	10,000	3,300	14,450	9,600	2,250	46,600	1,779
1965--	8,800	10,600	3,600	16,050	10,700	2,400	52,150	1,990
1970--	10,700	11,300	3,900	18,350	11,900	2,475	58,625	2,238
1975--	12,800	12,100	4,300	21,250	13,300	2,525	66,275	2,530
1980--	15,100	13,000	4,700	24,750	14,900	2,550	75,000	2,863

[1] These estimates are projections of past trends in the respective consumer categories, adjusted and revised for projections by the Bureau of the Census of population growth, for forecasts of gross national product, for estimates by the Federal Power Commission of power requirements to 1980, for expansions in the steel industry as indicated by steel-industry leaders, and for other factors on which data are available at present.

[2] Includes estimated imports as follows:

Year	Trillion B.t.u.	Bituminous-coal equivalent (million tons)
1955	2,755	105
1960	3,500	134
1965	4,500	172
1970	5,500	210
1975	6,500	248
1980	7,500	286

TABLE 5. - Potential contribution of bituminous coal and lignite to estimated future energy requirements on the basis of varying rates of coal's participation in the total energy market[1]

Year	Estimated total energy requirements, in millions of net tons bituminous-coal equivalent	Share of total energy market (million net tons)					
		30 percent	35 percent	40 percent	45 percent	50 percent	65 percent
1960--	1,779	533	622	711	800	889	1,156
1965--	1,990	597	697	796	896	995	1,294
1970--	2,238	671	783	895	1,007	1,119	1,455
1975--	2,530	759	886	1,012	1,139	1,265	1,645
1980--	2,863	859	1,002	1,145	1,288	1,432	1,861

[1] In 1955 estimated total energy requirement in bituminous-coal equivalent was 1,573 million net tons; bituminous coal supplied 29.9 percent.

Coal's decline. - As indicated by figure 1, the contribution of bituminous coal to the total energy market declined from 63.2 percent in 1925 to 29.2 percent in 1954, having last held the majority position as energy supplier in 1943. Bituminous coal's changed position in the energy market is shown by the fact that the decline has been absolute as well as relative; coal contributed 3,355 trillion B.t.u. less in 1954 than in 1925. Estimated coal production for 1955 was 470 million tons, indicating that coal regained part of this market during the year.

Coal's potentials. - If bituminous coal's contribution to the total energy market in 1975 continues to be the present 30 percent, demand in that year would be 759 million tons. The potential demands for other years and percentages are given in table 5.

COAL RESERVES

The estimated recoverable reserves of bituminous coal and lignite, as of January 1, 1953, are over 1,800 times the average annual rate of production during the past 10 years. Accordingly, from these coals alone the United States is assured an abundant supply of energy for centuries ahead.

Table 6 indicates the remaining coal reserves of the United States as of January 1, 1953, by rank, tons, and B.t.u. Table 7 shows the reserves by States.

TABLE 6. - Remaining coal reserves of the United States, January 1, 1953[1/] [2/]

Rank	Estimated total reserves remaining in the ground, January 1, 1953 (million net tons)	Estimated recoverable reserves, January 1, 1953, assuming 50 percent recovery (million net tons)	Estimated recoverable reserves, January 1, 1953, assuming 50 percent recovery (quadrillion B.t.u.)
Bituminous coal	1,049,457	524,729	13,643
Subbituminous coal	372,934	186,467	3,543
Lignite	463,356	231,678	3,105
Anthracite and semianthracite .	13,992	6,996	178
Total	1,899,739	949,870	20,469

1/ Averitt, Paul, Berryhill, Louise R., and Taylor, Dorothy A., Coal Resources of the United States, Geol. Survey Circ. 293, (1953), p. 1.

2/ Does not include any potential undiscovered reserves.

Location. - The location of coal production has both affected and been affected by the location of energy markets. Although this still is a potent force, particularly with regard to established industrial markets, it has been minimized in recent years by the tremendous advancements of petroleum and natural gas in the energy market. The location of coal production will be affected further by changes that develop in such factors as the source and availability of different qualities of coals and of other industrial raw materials (iron ore, water, etc.), in fuel-burning efficiencies and electric power transmission, and technological developments which will bring changes in the "form" in which coal energy and coal products are produced, transported, and utilized. The significance of location of the widely differing kinds and qualities of coal reserves, as related to their markets, is indicated by the comprehensive crisscross pattern of bituminous-coal distribution, in which coals from various states move to and through other coal-producing states.

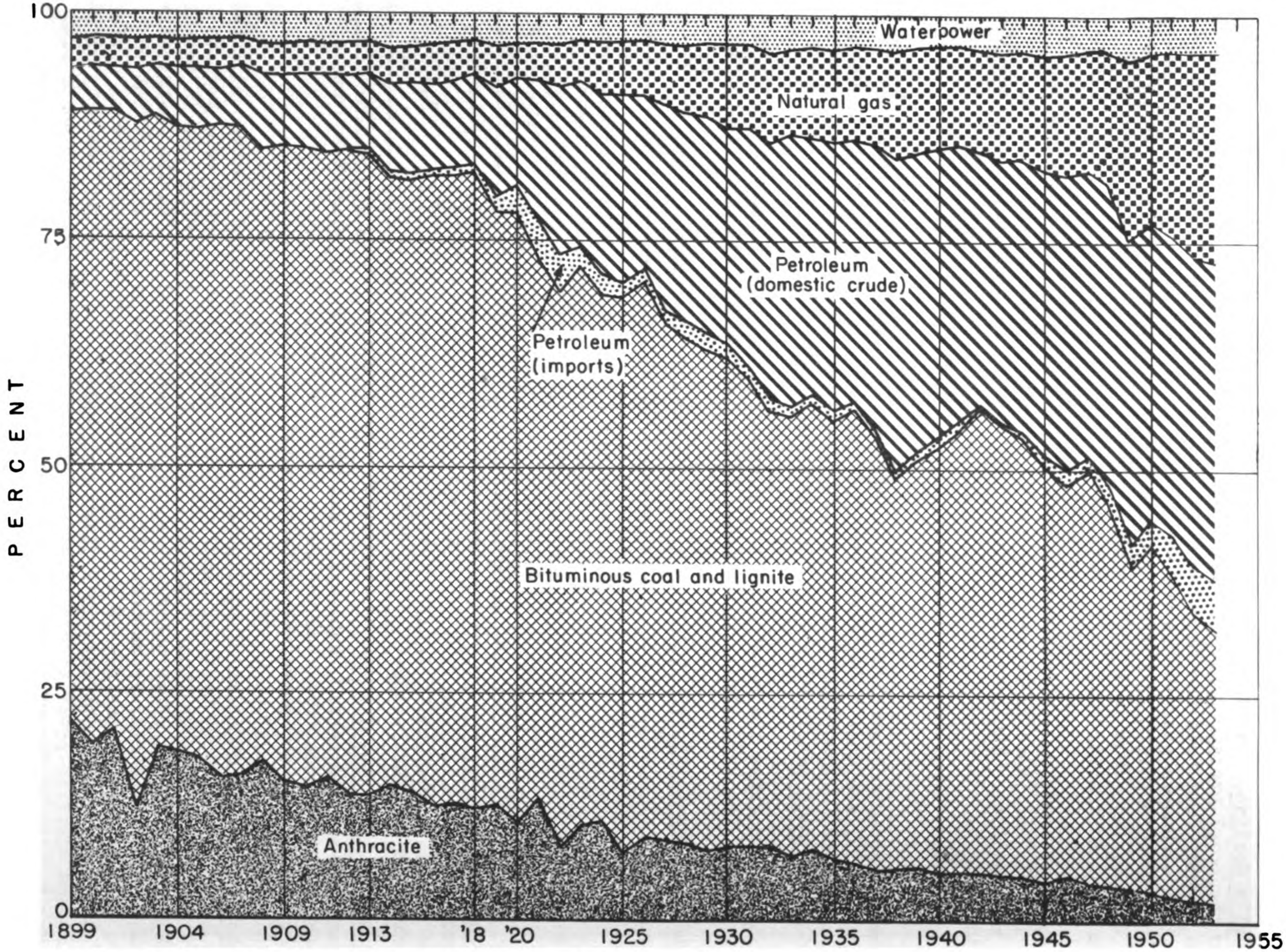

Figure 1. - Percentage of total British thermal units equivalent contributed by the several sources of energy in the United States, counting waterpower at the prevailing fuel equivalent of central stations in each year, 1899-1953.

TABLE 7. - Coal reserves of the United States, January 1, 1953, by States (million net tons)

State	Recoverable reserves, assuming 50-percent recovery
Alabama[1]	32,924
Arkansas	764
COLORADO[2]	49,719
GEORGIA	38
ILLINOIS	68,504
INDIANA	17,607
Iowa	14,232
KANSAS	10,381
Kentucky	59,487
MARYLAND	598
MICHIGAN	110
Missouri	39,414
MONTANA	110,860
NEW MEXICO	30,754
NORTH CAROLINA	55
NORTH DAKOTA	175,378
Ohio	41,486
Oklahoma	27,309
PENNSYLVANIA	36,189
SOUTH DAKOTA	1,015
Tennessee	12,493
Texas	15,438
Utah	46,452
VIRGINIA	5,417
Washington	31,794
WEST VIRGINIA	52,881
WYOMING	60,395
Other States	8,176
Total	949,870

1/ Reserve estimates of States in lower case letters were prepared by, or under the direction of, M. R. Campbell before 1928.

2/ Reserve estimates of States in capital letters supersede earlier estimates by M. R. Campbell.

Just as in the past the availability of coal has strongly influenced the location of coal-consuming industries, so will these factors have equal, or perhaps greater, significance in the future location of energy-consuming industries - and special importance in determining whether those industries will use coal or some other source of energy. Accordingly, if coal is to attain its share in the tremendously expanding energy markets of the future, the location of reserves will be an increasingly important consideration in planning research and development with respect to new techniques for mining, preparing, transporting, and utilizing coal. It is conceivable that entirely new practices in these phases of coal technology will be necessary to achieve the desired end.

Special purpose coals. - One of the principal considerations that influenced location of the large steelmaking installations in the Pittsburgh, Pa., and Birmingham, Ala., areas was the ready availability of large reserves of coal having the desired chemical and physical characteristics. The heavy demands of industry for these coals in the past has brought about serious depletion of deposits, and as the coal sources become more distant the delivered cost of the product increases. In many areas, concurrent with the lengthened transportation haul, there has been a steady deterioration in coal quality as mined. While adequate reserves are available for many years of steelmaking, it is evident that close by, premium-grade deposits are seriously depleted and the remaining reserves will require intensive preparation and careful blending to approach the quality of the metallurgical fuel that formerly was used by industry. This condition has led to an intensive search for additional coal reserves.

Because of the effect of quality and location of reserves on the share of the total energy market, that coal might obtain in the future, more coals of suitable quality must be found where needed.

Research Possibilities

The following specific projects would assist in attaining this goal:

1. Investigate the formation and development of coal beds and the effects of physical, chemical, and biologic factors (see also 204).
2. Develop new geophysical methods of finding and estimating extent of coal deposits.
3. Map reserves more intensively, including information on variations in quality of coal with location and on the nature of minerals associated with coal.

PRODUCTION AND DISTRIBUTION

Mining

Trends in bituminous-coal and lignite production for the period 1925-55, by mining methods, are summarized in table 8.

Underground mining. - During the period 1925-55 hand loading declined from 98.8 percent to approximately 14.7 percent of underground production, while conversely mechanical loading increased from 1.2 percent to 85.3. By 1953 mobile loaders, which virtually eliminate hand shoveling, loaded 84 percent of underground mechanically-loaded production; hand-loaded conveyors 9 percent; conveyors equipped with self-loading heads 3 percent; and continuous mining machines, which both mine and load the coal, 4 percent.

TABLE 8. - Production of bituminous coal and lignite in the United States, by method of mining, 1925-55 (thousand net tons)

Year	Underground mines			Auger mines	Strip mines[1]	Total
	Hand loaded	Mechanically loaded	Total			
1925--	496,939	6,243	503,182	---	16,871	520,053
1926--	545,899	10,545	556,444	---	16,923	573,367
1927--	482,885	16,500	499,385	---	18,378	517,763
1928--	459,397	21,559	480,956	---	19,789	500,745
1929--	476,859	37,862	514,721	---	20,268	534,989
1930--	400,702	46,982	447,684	---	19,842	467,526
1931--	315,595	47,562	363,157	---	18,932	382,089
1932--	254,252	35,817	290,069	---	19,641	309,710
1933--	277,539	37,821	315,360	---	18,270	333,630
1934--	297,145	41,433	338,578	---	20,790	359,368
1935--	301,549	47,177	348,726	---	23,647	372,373
1936--	343,985	66,977	410,962	---	28,126	439,088
1937--	330,280	83,500	413,780	---	31,751	445,531
1938--	233,045	85,093	318,138	---	30,407	348,545
1939--	246,421	110,712	357,133	---	37,722	394,855
1940--	269,734	147,870	417,604	---	43,167	460,771
1941--	272,411	186,667	459,078	---	55,071	514,149
1942--	282,587	232,903	515,490	---	67,203	582,693
1943--	260,687	249,805	510,492	---	79,685	590,177
1944--	244,489	274,189	518,678	---	100,898	619,576
1945--	205,118	262,512	467,630	---	109,987	577,617
1946--	175,617	245,341	420,958	---	112,964	533,922
1947--	193,072	298,157	491,229	---	139,395	630,624
1948--	164,206	295,806	460,012	---	139,506	599,518
1949--	109,447	222,376	331,823	---	106,045	437,868
1950--	120,119	272,725	392,844	---	123,467	516,311
1951--	111,791	304,256	416,047	N.a.[2]	117,618	533,665
1952--	87,431	268,994	356,425	1,506	108,910	466,841
1953--	71,222	278,329	349,551	2,291	105,448	457,290
1954(est)	52,000	244,000	296,000	3,000	93,000	392,000
1955(est)	52,000	302,000	354,000	6,000	110,000	470,000

[1] Includes power strip pits proper and excludes horse stripping operations and mines combining stripping and underground in the same operation for 1914-42, inclusive. The years 1943-53, inclusive, include data on all strip mines.

[2] Data not available.

Although these advancements represent progress of a high order, they also serve as a warning. Since this has been the major field of opportunity for cost reduction, the opportunities are limited as far as further replacements of hand loading are concerned. For the underground production that is not already mechanized a large portion is not amenable to mechanization because of geological and other physical deterrents. The impact of these circumstances on future mechanization is at least twofold. First, future cost reduction will depend largely on improvements over present mechanical methods; second, other activities in the mining process, including increased efficiencies in hand loading mines, will have to be subjected to more intensive research and development.

Auger mining. - A relatively recent development - auger mining - is used in coal seams that are exposed in strip mining but which are impractical to mine economically by stripping methods when the overburden becomes too thick. By 1953 auger mining furnished 0.5 percent of the total bituminous-coal and lignite production. However, since it is limited in its application to certain phases of strip mining, ultimate recovery by this means will be only a fraction of the tonnage strip mined. Although average productivity was 25 tons per man per day, as compared with 18 tons at strip mines and 7 tons at underground mines, it is a field in which there are numerous research opportunities for increasing recovery and productivity.

Strip mining. - Strip mining has grown rapidly, having increased from 3.2 percent of the production in 1925 to around 23 percent in 1955. The principal advantage of stripping is that output per man per day is approximately three times larger than in underground mines, which results in generally lower costs. Further growth of strip mining will be made possible by continuing development of larger and better equipment, combined with improved power drills for shot holes in overburden and larger, sturdier trucks for hauling the coal from the strip pits to tipples and ramps. There are limitations on the amount of strip mining, since it is believed that readily available strippable coals, strategically located geographically are limited.

Thickness of seams. - The overall operating efficiency of bituminous-coal mining is affected by many physical conditions; one of the most important is the thickness of the coal seam. Table 9 summarizes the thickness of seams mined in 1950.

TABLE 9. - Percentage of total production of underground mines in the United States, 1950, by thickness of seams mined

Thickness of seams mined, feet	Production, percent
Less than 2	0.2
2 to 3	4.5
3 to 4	27.6
4 to 5	19.7
5 to 6	15.0
6 to 7	16.1
7 to 8	8.5
8 and over	8.4
Total	100.0

The coal seam of moderate thickness presents the least mining difficulties. Any thinning limits production, decreases recovery, and therefore increases cost.

Thickening of the seam in underground mining also increases cost using present mining machines and practices, since it becomes necessary to maintain larger pillars; timbering then becomes more difficult and roof control even more so. There are opportunities for research on more economic methods for mining thin and thick seams with maximum conservation of coal.

Number and size of mines. - The number of mines has fluctuated roughly with the relative production of the coal industry. When there was a heavy demand for coal, many small mines came into operation. Usually these smaller mines were the first to shut down when coal markets began to decline, both because of the lack of markets and their inability to compete with the larger, more efficient, mechanized mines. Table 10 shows the number of bituminous-coal mines in the United States, by years. It is estimated that after dropping further in 1954, the number of mines in 1955 approximated 6,500.

The trend toward larger, more efficient mines is a direct result of increasing competition for the coal market. Continued research on improved, more economic mining methods should develop a larger, more efficient mining industry.

Productivity. - The high degree of underground mechanization and surface stripping has had a profound effect on output per man per day. Productivity has increased between 1925 and 1955 from 4.52 to about 10 tons per man-day.

Capacity. - Many qualifying factors must be applied to the determination of the theoretical capacity of bituminous coal and lignite mines (table 10). Many intangibles and complexities are involved (manpower, hours and days of work, availability of machinery, materials, supplies, transportation facilities, etc.) so that an appreciable margin below "estimated" capacity should be considered as "attainable" production. Although a standard of 280 days has been used in the past for calculating potential annual capacity, that figure has never been attained and has been closely approached only once.

The "estimated" capacity of bituminous coal and lignite mines in 1953 for 280 days of operation was only 670 million tons, and for 225 days of operation 538 million tons, compared with an actual production of 457 million tons in an average of 191 days of operation.

By 1965 (table 5) the demand for bituminous coal could be expected to be 600 to 800 million tons. For each 5 years thereafter the demand is estimated to increase an additional 80 to 120 million tons. The present maximum capacity will have to be increased substantially to meet these new demands. The research on new and improved mining methods and equipment and on better conservation practices with increased safety must be started immediately to be ready to meet this anticipated increase in capacity by 1965.

Technological Problems and Research Possibilities

The survey of current coal research showed a reported annual expenditure of $3,038,700, with 140 professional men employed on all phases classed as mining research. Although this expenditure is 17.5 percent of the total amount spent for coal research last year, almost all of the reported research expenditures were by manufacturers of mining equipment. Many coal producers adapt equipment and mining methods to their own conditions but do not show such development-type work as research in reporting their activities.

TABLE 10. - Number of bituminous-coal and lignite mines in the United States and potential productive capacity at 225 and 280 days' work, 1925-53

Year	Number of mines	Days actually worked	Potential capacity (million net tons)	
			225 days	280 days
1925--	7,144	195	601	748
1926--	7,177	215	600	747
1927--	7,011	191	610	759
1928--	6,450	203	555	691
1929--	6,057	219	546	679
1930--	5,891	187	562	700
1931--	5,642	160	538	669
1932--	5,427	146	477	594
1933--	5,555	167	449	559
1934--	6,258	178	454	565
1935--	6,315	179	468	582
1936--	6,875	199	497	618
1937--	6,548	193	519	646
1938--	5,777	162	484	602
1939--	5,820	178	499	621
1940--	6,324	202	513	639
1941--	6,822	216	535	666
1942--	6,972	246	533	663
1943--	6,620	264	503	626
1944--	6,928	278	501	624
1945--	7,033	261	498	620
1946--	7,333	214	562	699
1947--	8,700	234	607	755
1948--	9,079	217	622	774
1949--	8,559	157	628	781
1950--	9,429	183	635	790
1951--	8,009	203	591	736
1952--	7,275	186	565	703
1953--	6,671	191	538	670
1954(est)	6,000	185	477	593
1955(est)	6,500	217	487	606

The following specific projects are proposed to carry out the required research program for meeting the needs of the industry for producing coal. Each of the solutions found should increase safety in mining and improve conservation practices.

Mining methods and equipment

4. Develop rugged mining machines requiring low maintenance and with power and cutting ability sufficient for rapid development work and maneuverable enough for retreat mining.
5. Study means of providing automatic directional control for continuous mining equipment.
6. Develop means for remote control of continuous miners that are in view of the operator.
7. Develop improved equipment for conventional mining where continuous-type equipment is not applicable.
8. Standardize mining equipment to lower maintenance and supply costs.
9. Develop improved mining methods and machines for use in thin and thick coal seams.
10. Develop improved methods of selective mining to remove the more valuable sections of the coal bed separately (see also 131).
11. Study the influence of physical characteristics of coal beds, roof, and bottoms on the problems of mining and the development of improved mining equipment.
12. Investigate means for rapidly strengthening soft bottoms or soft spots to support heavy equipment.
13. Study economic disposal of refuse underground.

Underground haulage

14. Develop new face conveying methods and new equipment to provide continuous transport of coal from the face to main haulage.
15. Study improved methods of transportating supplies to the working face.
16. Study new means of mainline transportation, including hydraulic and pneumatic methods (see also 71, 146).

Roof control

17. Conduct research on roof control to provide better roof bolting methods, help in the development of better means of support and develop a guide for selecting the type of roof support that will provide adequate permanence of control, based upon the life of the area being worked.
18. Develop simple means of indicating stress on roof bolts or on other roof-control devices.

19. Determine conditions under which auxiliary supports to roof bolts are required.

20. Develop temporary roof supports that are lightweight, easily installed, and easily reclaimed.

21. Investigate means of controlling newly exposed roof near the working face.

22. Study problems of roof control during longwall mining, especially problems resulting from use of new planer-type mining equipment.

Ventilation

23. Study the effect of mine layout on ventilation problems.

24. Develop improved methods for degasifying coal beds, including efficient use of the recovered gas.

25. Develop methods for pneumatically removing dust at the working face.

Power

26. Develop improved methods of supplying power at the working face, including the economic and technical aspects of AC versus DC power.

Lighting

27. Develop improved lighting underground approaching factory standards of illumination.

Causes and control of acid mine water. - Acid drainage from worked-out mines, or sections of mines above drainage level, is a serious and difficult water-pollution problem. Research has shown that drainage from strip mines can usually be effectively controlled; but the prevention of acid drainage from worked-out underground mines that are above stream level is a very difficult problem. The Commonwealth of Pennsylvania and the coal industry have spent around $400,000 to obtain fundamental data on the formation of acid drainage. Important advances have been made, but the problem is far from solved.

28. Develop additional fundamental data on the causes and prevention of acid mine drainage.

Strip mining

29. Develop improved machines and methods for removing overburden and coal.

30. Develop methods and machinery for dry blast-hole drilling.

31. Develop more durable materials for bucket teeth and similar applications.

32. Develop improved equipment and methods for recovering coal under overburden too thick to be removed economically by stripping, including the development of improved methods for auger mining.

Underground Gasification

European and particularly Russian investigations in underground gasification have been conducted with some degree of success for about 20 years. It is reported that the Russians have some commercial installations; other European countries have not carried their work beyond the experimental stage.

The objective of the underground research is development of processes for gasifying unmined coal to provide energy from coal in a more convenient form, to reduce the cost of bringing energy to the surface and to the point of consumption, to reduce the hazards associated with underground coal mining, and to utilize the poorer seams of coal not now economical to mine. Seams in which the quality of the coal is poor, the thickness is insufficient for economic mining, and the type of roof rock is such that very expensive methods of control would be required might all be suitable for underground gasification.

Two types of gas can be made by underground gasification. The first is a hot, producer-type gas, which could be used as a source of power either in conventional boilers or in a gas turbine. Such gas might also be used in one of the steps required for producing synthesis gas (water gas), which is used for producing high-B.t.u. gas, chemicals, and synthetic liquid fuels. It is possible that by using oxygen instead of air, underground gasification could produce directly a synthesis gas, that could be used for the purposes described above.

Although some progress has been made in this country and abroad in understanding the factors to be considered in underground gasification operations, a number of technological problems continue to delay application of this process in this country. Various methods have been proposed for establishing gasification passages in the coal seam. Of these methods, the most promising appear to be electrolinking and hydraulic fracturing. To make the gasification process economical, further research directed toward reduction of costs is required on methods for seam preparation, burning of the coal, and collection of the make gases.

Technological Problems and Research Possibilities

33. Develop improved methods for seam preparation, using electrolinking, hydraulic fracturing, or other methods.

34. Study factors that determine the voltage, total energy requirements, and path of the linkage.

35. Study effect of rank of coal (coking and noncoking) on electrolinking.

36. Investigate optimum pressure required for hydraulic fracturing, the type of liquids and solids suitable for coal fracturing, methods for retaining the fracture in the coal bed, and the effect of strata above and below the coal bed on the fracturing.

37. Investigate the control of the inflow of water on the gasification system.

38. Study methods for reducing leakage losses of the product gas.

39. Investigate methods for developing the gasification passage by combustion under pressure.

40. Investigate combustion control to obtain the maximum quantity of gas of desired quality.

41. Study the effects of seam preparation and combustion methods on the extent of coal utilization.

42. Study the economics of underground gasification as affected by type of linkage, depth and thickness of seam, quality of coal, and gasification pattern.

Preparation

The significant advances that have been made in mechanical cleaning have been motivated by the need for upgrading coal to meet both specific market requirements and the competition from oil and natural gas. With mechanical loading it is virtually impossible to remove the coal selectively by benches or to free the loaded product underground from extraneous material picked up during the mining and loading cycle. Therefore, increasing dependence is placed upon the preparation equipment to remove effectively not only the impurities associated with the coal matter but such other extraneous matter as has been added mechanically during mining. This change in mining practices, together with the exploitation of inferior grade reserves, has imposed an increasingly heavy burden on the washing process. During the last 2 decades the ratio of refuse to raw coal at bituminous coal cleaning plants has increased approximately twofold.

Even in noncompetitive markets, however, advanced mechanical cleaning was necessary, such as in preparing better coals for blending to compensate for depletion of premium-grade metallurgical coals. In addition, much of the premium coking coal readily available to the steel industry has been depleted, and of the remaining reserves of Pittsburgh-bed coal in Pennsylvania approximately 90 percent is found in the southwest corner of the State where sulfur content is known to be excessive. Some of the better known sources of low-volatile coals are already exhausted. With depletion of the better grade coals that could be marketed after hand preparation at the face, mining operations have been shifting to reserves that require thorough mechanical cleaning to meet the quality limitations imposed by the metallurgical market.

Mechanical cleaning. - The quantity of bituminous coal mechanically cleaned increased from 28 million tons (5 percent of the total production) in 1927 to 282 million tons (60 percent) in 1955. Refuse handled at cleaning plants increased from 3 million tons in 1929 to 54 million tons in 1953. The ratio of refuse to raw coal increased from 9 percent in 1929 to 18 percent in 1953. Increased mechanical loading has been the major reason for both increased mechanical cleaning and the additional refuse. Other important factors were (1) decreased demand for large lumps, (2) increased demand for stoker sizes, (3) increased practice of "full-seam mining," (4) depletion of some of the higher quality coals, and (5) general demand for cleaner coal.

The anticipated increased demand for coal and the factors mentioned above indicate a sharp rise in future of the tonnage of coal mechanically cleaned and in the amount of refuse that must be removed. Intensive research on improved and more economic methods of mechanical cleaning will be required to meet these new demands on the preparation plant.

Mechanical crushing. - There are two prime objectives in crushing bituminous coal: One is to reduce lump to sizes that will facilitate handling and cleaning, and the other is to reduce sizes to meet market requirements. Before about 1930 the larger sizes of lump were at a premium, and there was only a small amount of mechanical cleaning; therefore little coal was crushed. After about 1930 the steadily increasing percentage of bituminous coal loaded with power shovels at strip mines increased the large lumps of coal. At the same time in underground mining the increase in mechanical loading increased the amount of refuse, and in order to prepare a suitable product the coal had to be crushed before it could be mechanically cleaned properly. In addition, the increased use of mechanical stokers that require specific sizes, usually the smaller sizes, greatly stimulated the necessity for crushing of coal.

The growth of mechanical crushing since 1940 is shown graphically in figure 2. The tonnage crushed has increased threefold from 1940 to 1953.

Technological Problems and Research Possibilities

Despite the importance of efficient coal preparation to yield a marketable product, the survey of current coal research showed that coal preparation research involves a reported annual expenditure of $606,400, with 45 professional men employed. This sum is only 3.4 percent of the total expenditure for coal research last year. The technological difficulties involved in cleaning and drying the fine sizes are reflected in the substantial proportion of coal-preparation-research funds that are devoted to this field of activity. With the possibility that within a few years virtually all coal will be mechanically cleaned, research in coal preparation must be accelerated so that industry can continue to meet the critical specifications imposed by the coal consumer.

Coarse-Coal Cleaning

Dense-medium washing. - During the last decade one of the major developments in coal preparation was the introduction and widespread use of cleaning systems using a suspension of magnetite in water as the dense separating medium. Although the process permits separation at specific gravities previously unattainable in commercial practice, it has some serious limitations. Dense-medium processes are not effective for cleaning the entire mine-run size range. Coal particles approximately 1/4-inch and smaller must be removed from the raw-coal feed; and, if these finer sizes require mechanical cleaning, a separate fine-coal cleaning system must be installed. Magnetite is rather expensive, and its replacement with some less costly material, which would not require expensive reconditioning before reuse in the washing system and still permit precise separation of coal over a wide specific-gravity range, is desired.

To improve the operation of dense-medium equipment, there is need for a better understanding of the effect of operating variables upon washing efficiency, of the behavior of coal particles in the dense medium, and of the effect of viscosity of the medium when treating the smaller sizes of coal. A detailed study of the effects of medium viscosity will probably have to await the development of a suitable viscometer.

Specific research projects for study of dense mediums are:

43. Develop a viscometer to measure viscosity of dense mediums.

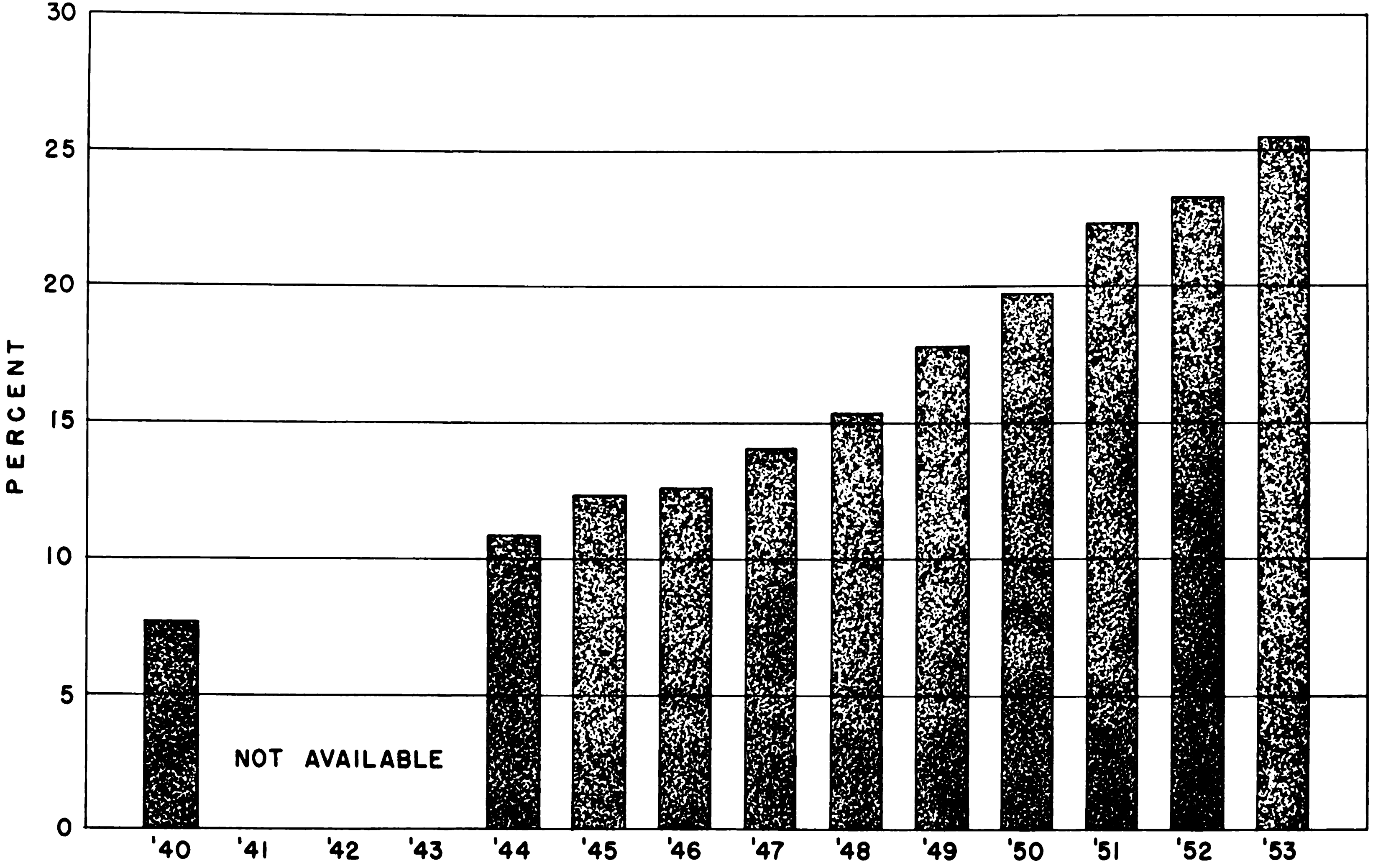

Figure 2. - Percentage of total production of bituminous coal and lignite crushed at mines in the United States, 1940 and 1944-53.

44. Study physical characteristics of dense mediums and their effect upon cleaning efficiencies.

45. Develop other dense mediums.

46. Extend effectiveness of dense-medium cleaning to entire mine-run size range.

Jig washing. - The jig is one of the most popular types of coal cleaner, but to obtain even better operating efficiency the following studies are required:

47. Determine effect of impulse cycle on separation.

48. Investigate influence of bed action on both stratification and capacity.

49. Develop improved means to control and remove impurities.

Fine-Coal Cleaning

Pneumatic cleaners. - Pneumatic cleaners prepare a clean product that requires neither drying nor dewatering, but they are not as efficient as wet-cleaning methods. In addition, the feed to a pneumatic cleaner must be carefully controlled with respect to variations in surface moisture content. With the increased use of water at the working face, the raw-coal feed must sometimes be dried thermally to achieve effective separation in the pneumatic cleaner. Specific research possibilities are:

50. Study conditions under which it is economically advantageous to predry coal and clean pneumatically rather than to wet wash and then dry coal.

51. Develop improved pneumatic coal-cleaning methods, especially ones that are not susceptible to variation in surface moisture.

Wet-concentrating tables. - The rapid growth of dense-medium cleaning of coarse coal has been accompanied by the greatly expanded use of wet tables for cleaning the fines. Effective automatic controls have never been developed for wet tables, and the capacity of the tables with respect to the space required is disproportionate to that of other washing devices. Specific research possibilities are:

52. Investigate design changes in table construction to increase capacity.

53. Study table stratification in relation to operating variables to develop automatic controls.

Froth flotation. - As a means of preparing marketable fine sizes (minus-14-mesh), froth flotation is becoming more popular. To understand better the principles of froth flotation, the effects of heats of wetting, angles of contact, aeration, and changes in cell design upon their cleaning efficiency and capacity a few variables merit further study. Specific research possibilities are:

54. Use froth flotation theory to evaluate the effect of operating variables upon performance.

55. Use froth flotation to concentrate certain petrographic constituents of coal (see also 150).

Drying and dewatering. - One of the principal problems in coal preparation is economic removal of moisture from fine coal. The problem has been accentuated by the increased proportion of fines in the product entering the cleaning plant as a result of increased mechanization underground, lack of adequate disposal areas in the vicinity of the mining operation, rigid enforcement of air and stream pollution ordinances, and increased market demand for the smaller industrial sizes of coal. It is reported that present methods of thermal drying are relatively expensive and somewhat hazardous, and at times pose an air-pollution problem. Specific research possibilities are:

56. Study various polymers, wetting agents, and use of sonics and ultrasonics to improve flocculation and mechanical drying of coal.

57. Develop improved equipment and methods for thermal drying of fine coal.

58. Study the effect of bin design and wetting agents on gravity drainage of coal.

Crushing and blending coal

59. Examine the basic principles of coal breakage to reduce the energy required for crushing and to control the size composition of crushed materials (see also 142).

Performance testing of equipment. - Although the individual units of coal preparation equipment usually are well designed and capable of performing efficiently, plant layout has been neglected at times, and the full potential of the individual cleaning units has not been realized owing to mediocre performance of auxiliary equipment. Improved performance of auxiliary units of coal preparation equipment (screens, conveyors, belts, crushers, feeders, etc.) could be expected through a detailed investigation of their performance characteristics. Virtually all coal-cleaning processes and some auxiliary operations depend upon the mass movement of particles in a fluid - water, air, or dense medium; however, the physical laws governing such phenomena are obscure, and the limited knowledge in this area hinders rational design of coal-cleaning equipment. Specific research possibilities are:

60. Study performance characteristics of auxiliary coal preparation units (screens, crushers, belts, conveyors, feeders, etc.).

61. Study the use of electrostatics, electronics, x-rays, and optics for improved coal cleaning.

62. Develop a continuous method for recording moisture and ash content in the raw-coal feed and in the product (see also 151, 201).

63. Study sources, extent, and prevention of size degradation in the preparation plant (see also 75, 144).

64. Investigate means of dust control in the units of preparation equipment.

65. Study the influence of characteristics of solids on hindered settling in water, air, and dense medium.

Sulfur removal from coal by chemical means. - By present coal-cleaning processes, sulfur in the form of organic compounds intimately associated with the coal matter and as fine divided sulfides is not removable. Means of reducing this sulfur would make available for metallurgical use large reserves of coal that at present are unsuited to that purpose. A specific research possibility is:

66. Study the removal of sulfur from coal by chemical methods (see also 128).

Salvage of valuable products from washery refuse. - The cost of coal preparation could be reduced if some return could be realized from the material discharged to refuse by the washery. Precise control over the washing equipment will reduce the amount of combustibles in the refuse to a minimum, and salvage of the fine coal from the slurries and sludges discharged from the washery would decrease the overall cost of preparation. A detailed study of the recovery of pyrites from coal washery refuse may lead to some method for reducing the carbonaceous matter associated with the recovered pyrites to tolerances that would be acceptable to the chemical industry. Likewise, although the manufacture of lightweight aggregate from a few types of coal washery refuse has been successfully developed, study of other types of washery refuse may result in the manufacture of a superior grade of aggregate. Carbon discharged with the refuse probably could be salvaged by separating the refuse into carbon-rich and carbon-free components and gasifying the former to recover fuel values. Specific research possibilities are:

67. Develop more economical methods of salvaging fine coal from washery water.

68. Study possible utilization of refuse material discharged from coal preparation plants, including production of lightweight aggregate and mineral wool, for fuel value by gasification or combustion, as an aggregate for asphaltic road materials, and recovery of sulfides for chemical use.

Surface treatment of coal. - Approximately 10 percent of the annual coal production is subjected to surface treatment at the mine to allay dust and to help prevent freezing during transit. To understand better the problem of coal freezing during transit, more information is needed with respect to the influence of climatic factors on the strength of frozen coal. These factors probably would vary with coals of different rank and size. Improved surface treatment agents for allaying dust would aid in greater acceptability of coal by the buying public. Specific research possibilities are:

69. Study factors influencing freezing of coal in transit and storage (see also 70, 72, 77).

70. Investigate improved surface treatment agents for allaying dust and freezeproofing coal (see also 77).

Transportation and Storage

Transportation

The method of shipping of coal from the mines not only has an important bearing upon the opening of mines but also upon the cost of transportation and the final price of the coal to the consumer.

Before about 1933 approximately 90 percent of the total production was shipped by rail. Since then the percentage, including the tonnage trucked to rail sidings, declined steadily to 79 percent by 1953. This decline has been due largely to increased shipments by water and to shipments by truck from the mine to the final destination (See fig. 3.)

Freight rates. - Since World War II there has been a steady trend upward in average railroad freight rates on bituminous coal - from $2.20 per ton in 1945 to $3.35 per ton in 1952. The average in 1955 was $3.21. The average cost of rail shipment is about 40 percent of the delivered cost of coal. Eighty percent of all coal is shipped by rail. On the other hand, through the use of pipelines, oil and natural gas have an advantage over coal in the matter of transportation cost and competitive opportunities.

Railroad-car supply. - Periodically the coal industry faces shortages in open-top railroad cars. During the latter part of 1955 the railroads had total shortages of gondola and hopper cars averaging over 9,000 cars daily. To the extent that enough cars are not available and well-distributed the coal industry will be unable to increase the market for coal even if it can be produced.

Storage.

Stocks of bituminous coal are accumulated in various places, although little or none is accumulated at the mines. Some stocks are built up at intermediate storage piles between mines and consumers, but the most important stocks are those on the upper Great Lakes docks, in the hands of industrial consumers, and in retail yards. Those in the hands of industrial consumers and retail yards in 1944-53 are shown graphically in figure 4, the wide variations between some months are due largely to strikes.

There are wide variations in stocks of soft coal held by the different classes of consumers as expressed in terms of days' supply. Over 100 days' supply are held by electric utilities and about 30 days' supply by the railroads. Retail yards have a decided seasonal variation in the size of their stockpiles; they build up in the summer months and decrease during the winter months.

In addition to carrying adequate stocks of coal to assure the continuity of normal operations, coal consumers are motivated in their purchases for storage by the need for protecting their fuel supplies in case of mine or transportation strikes or other emergencies, and by the desire to hedge against anticipated price changes. With respect to electric utilities, some States have legal requirements regarding the minimum days' supply that must be maintained.

The movement of coal into and out of storage can have a significant effect on coal production. Increases in consumer stocks during otherwise slow periods help to keep mines in operation and open-top cars in the coal trade.

Technological Problems and Research Possibilities

The survey of current coal research showed a reported annual expenditure of $97,900, with 5 professional men employed on all research that may be classed as relating to storage and transportation. This is about 0.6 percent of the total amount spent for coal research. Although the percentage of expenditures for research on storage and transportation is small, those intermediate steps between the mining and use of coal are extremely important from the standpoint of cost,

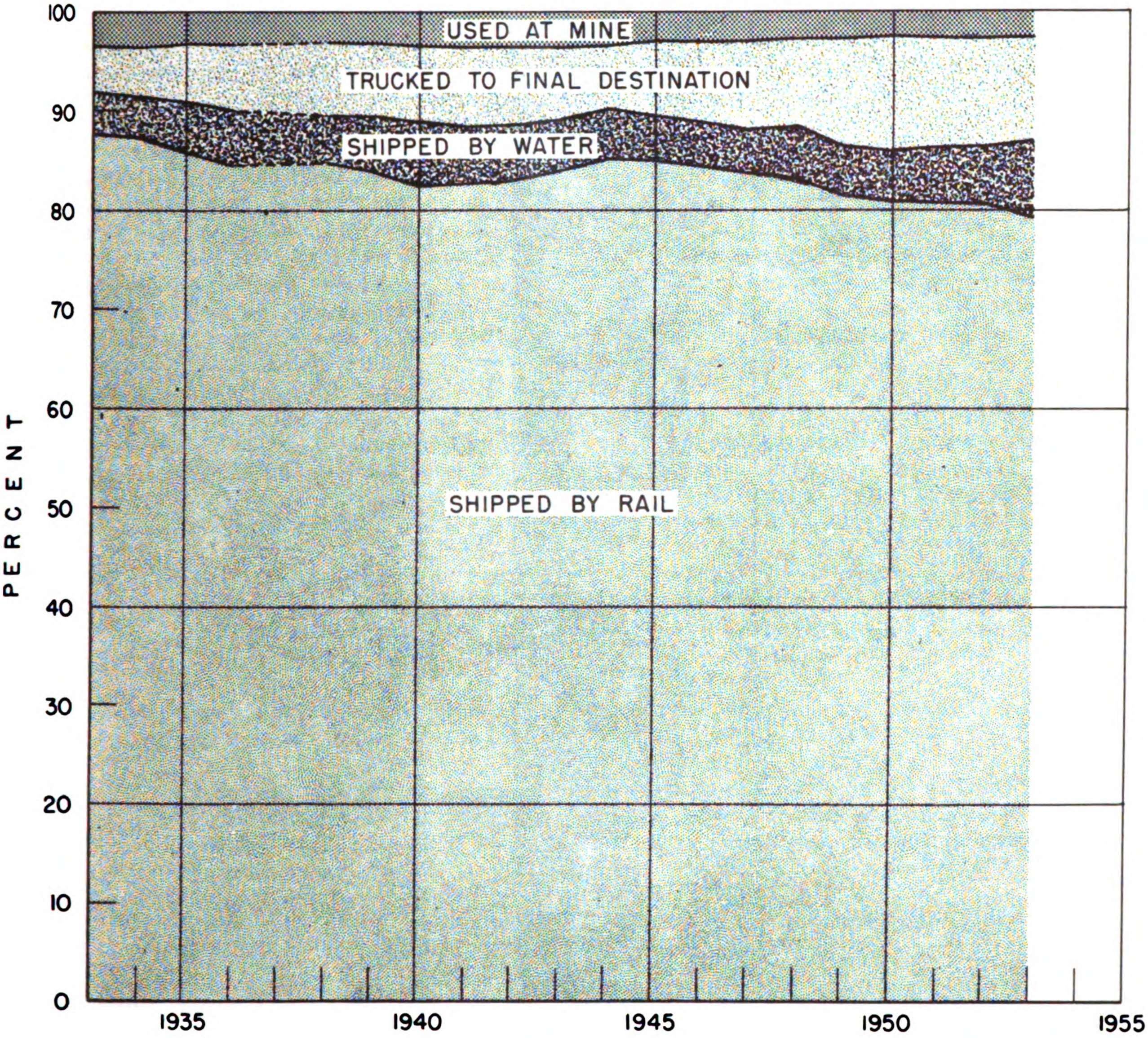

Figure 3. - Percentage of total production of bituminous coal and lignite, 1933-53, by method of shipment from mine, and used at mine.

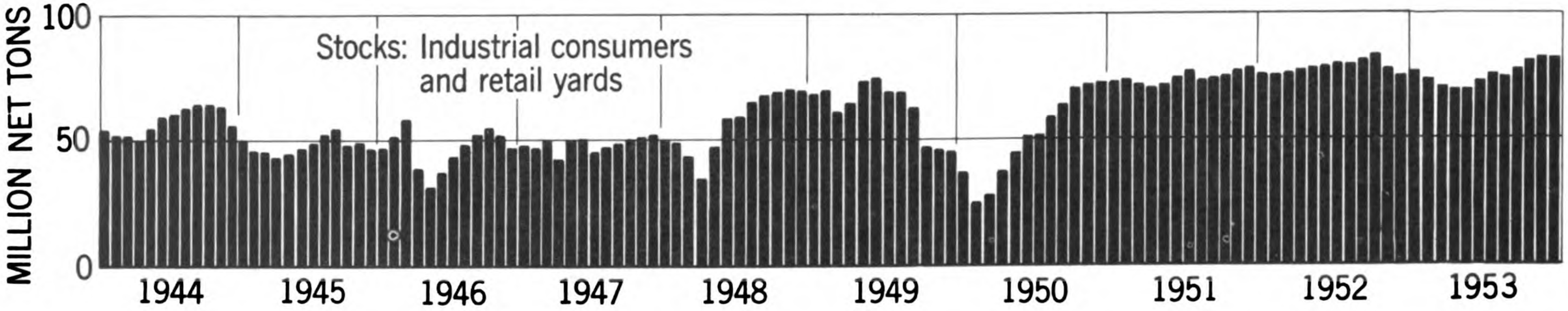

Figure 4. - Trends of stocks of bituminous coal and lignite in the United States, 1944-53.

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since handling and transportation charges in many cases equal or exceed the cost of coal at the tipple. Moreover, the coal industry has no control over this cost when coal is shipped by rail. The development of other cheap methods of transportation would reduce the cost to the consumer and open larger markets for coal.

Although most coals oxidize slowly during storage and transportation, losses from this cause are seldom large or particularly significant. However, special purpose coals, such as some coking coals, may change materially in carbonizing properties during storage. Moreover, some coals, particularly those of lower grade and rank, tend to fire spontaneously if not stored vary carefully, and most coals will ignite spontaneously in the pile under certain circumstances. Other losses or difficulties that may result from storage and transportation are size degradation, wind losses from storage piles and railroad cars, and freezing of coal in bunkers during severe winter weather. Specific research possibilities are:

71. Study and compare costs of transportation by various means, including hydraulic, pneumatic, and belt, and compare these, for various tonnages and distances, with water, rail, and truck haulage. This would include research and development work on hydraulic, pneumatic, and belt transport, where data are not already available (see also 16, 146).

72. Study the causes and cures for difficulties in moving coal, including study of flow characteristics of coal, effect of bin design, and effects of additives upon flow and freezing properties (see also 69, 70, 73, 90, 96, 144, 145).

73. Study efficient and economic methods for storing and handling coal and ash at industrial sites (see also 72, 90, 96, 144, 145).

74. Study the causes of spontaneous ignition and methods of alleviating it, including the effects of particle size, sulfur and moisture content, and effectiveness of additives, methods of piling, and sealing piles.

75. Study methods of alleviating degradation in handling (see also 63, 144).

76. Study the effect of storage on mineral matter and/or coking characteristics of coal.

77. Study freezeproofing of coals during storage (see also 69, 70, 72).

COAL MARKETS

Due principally to the increased availability and utilization of petroleum and natural gas, bituminous coal and lignite consumption in the United States dropped from a peak of 594 million tons in 1943 to 363 million tons in 1954 - a net decline of 231 million tons - from which it increased 60 million tons in 1955, reducing the net loss to 171 million tons. Concurrent with these heavy declines there have been pronounced shifts in the pattern of coal utilization. (see figure 5). Since 1943 there have been continuing losses in bituminous-coal shipments to railroads, retail dealers, general industrial plants (excluding electric power utilities), and steel and rolling mills (excluding coking coal). On the other hand, there has been an upswing in consumption by electric-power utilities and cement mills, as indicated below.

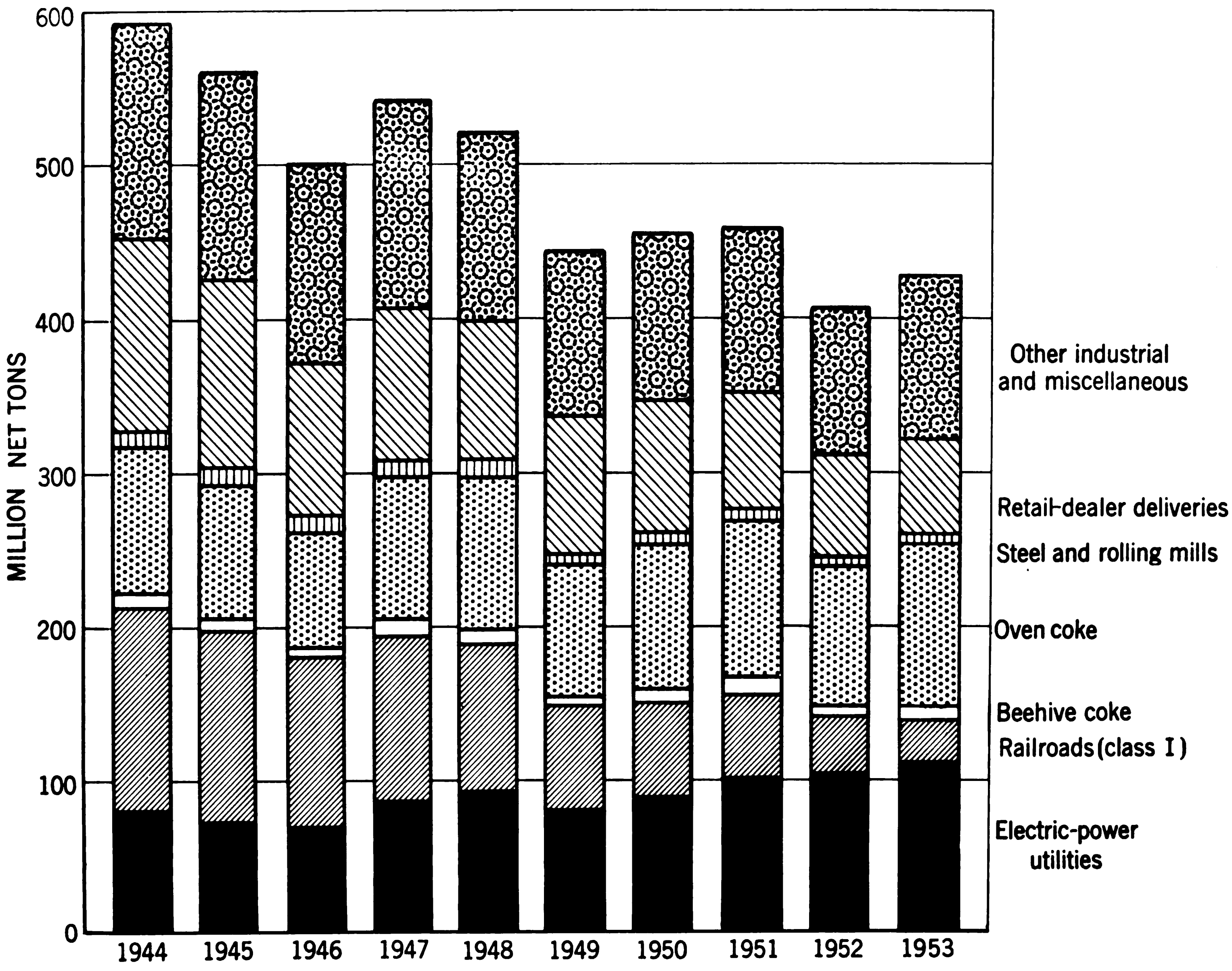

Figure 5. - Consumption of bituminous coal and lignite, by consumer class, with retail-dealer deliveries in the United States, 1944-53.

Power Generation

Public Utilities.

The phenomenal increase in demand for electric energy has resulted in a 250-percent increase in coal consumption by electric utilities during the past 30 years (from 40 to 140 million tons), including a 59 percent increase from 1950 to 1955, as indicated by table 11.

The demand for electricity has more than doubled every 10 years, but efficiency in coal consumption at electric powerplants has been increasing, having dropped from 3.20 pounds per kilowatt-hour in 1919 to 0.95 pound per kilowatt-hour in 1955.

From all quarters there are indications that, in keeping with our strongly advancing economy, the increasing demand for electric energy will continue indefinitely and that it will accelerate during the next several decades. Hydropower supplies only about 4 percent of the Nation's total energy requirements and is relatively limited in expansibility. On the other hand, oil and natural gas probably will continue to supply a sizable share of fuel to electric-power utilities for some time, since the potentials for our vast industrial economy to attract world surpluses of residual fuel oils, as well as crudes from which to produce additional residuals, are very great.

These factors are stressed because they can have a strong bearing on the extent to which coal is to share in the power markets of the future. They are part of the many and complex economic variables that accentuate the need for continually greater efficiency and lower costs in mining, preparation, transportation, marketing, and utilization of coal.

Potential Future Energy Demand

Estimated potential energy demands for electric-power utilities' generation from fuels, in trillion British thermal units and bituminous-coal equivalents, are indicated below for 5-year periods beginning in 1955 and ending in 1980.

	1955	1960	1965	1970	1975	1980
Trillion B.t.u.	5,265	7,000	8,800	10,700	12,800	15,100
Bituminous coal equivalent (million of net tons)	201	267	336	409	488	576

These estimates of total energy required to produce electric power at steam plants allow for increased efficiencies in fuel burning.

In 1954, the latest year for which complete data are available, bituminous coal supplied almost 63 percent of the total energy used in generating electric power.

Technological Problems and Research Possibilities

The survey of current coal research showed a reported annual expenditure of $1,121,800; 42 professional men were employed on the study of coal combustion (including power generation, industrial steam production and space heating). This amount, comprising only 6.4 percent of the total coal research expenditure, is surprisingly low when it is recognized that nearly 80 percent of the coal tonnage produced is sold for combustion.

TABLE 11.--Consumption of bituminous coal and lignite, by consumer class, with retail deliveries in the United States, 1925-55, in thousand net tons

Year	Electric-power utilities1/	Bunker foreign trade2/	Rail-roads3/ (Class I)	Coke plants		Steel and rolling mills	Cement mills4/	Other indus-trial5/	Retail deliv-eries6/	Total of classes shown7/
				Bee-hive	Ovens					
1925---	40,222	4,866	117,714	17,423	57,110	-	9/	261,858	-	499,193
1926---	41,311	7,736	122,823	19,225	63,647	-	9/	277,839	-	532,581
1927---	41,888	4,565	115,883	11,208	63,240	-	9/	263,017	-	499,801
1928---	41,350	4,294	112,382	7,018	70,166	-	9/	263,618	-	498,828
1929---	44,937	4,287	113,894	10,028	76,759	-	9/	269,650	-	519,555
1930---	42,898	3,497	98,400	4,284	65,521	-	9/	240,390	-	454,990
1931---	38,735	2,195	81,725	1,767	46,846	-	9/	200,601	-	371,869
1932---	30,290	1,350	66,498	1,030	30,887	-	9/	176,862	-	306,917
1933---	27,088	1,316	72,548	1,408	38,681	10,009	2,832	83,321	80,482	317,685
1934---	29,707	1,321	76,037	1,635	44,343	10,898	3,500	89,448	86,925	343,814
1935---	30,936	1,576	77,109	1,469	49,046	11,747	3,516	96,937	83,990	356,326
1936---	38,104	1,622	86,391	2,698	63,244	13,471	4,771	113,792	84,200	408,293
1937---	41,045	1,832	88,080	4,927	69,575	12,853	5,247	127,142	80,076	430,777
1938---	36,440	1,352	73,921	1,360	45,266	8,412	4,483	96,527	68,520	336,281
1939---	42,304	1,477	79,072	2,298	61,216	9,808	5,274	103,079	71,570	376,098
1940---	49,126	1,426	85,130	4,803	76,583	10,040	5,633	110,469	87,700	430,910
1941---	59,888	1,643	97,384	10,529	82,609	10,902	6,832	124,868	97,460	492,115
1942---	63,472	1,585	115,410	12,876	87,974	10,434	7,570	135,979	104,750	540,050
1943---	74,036	1,647	130,283	12,441	90,019	11,238	5,851	145,518	122,764	593,797
1944---	76,656	1,559	132,049	10,858	94,438	10,734	3,789	134,610	124,906	589,599
1945---	71,603	1,785	125,120	8,135	87,214	10,084	4,215	129,606	121,805	559,567
1946---	68,743	1,381	110,166	7,167	76,121	8,603	7,009	120,610	100,586	500,386
1947---	86,009	1,689	109,296	10,475	94,325	10,048	7,938	126,948	99,163	545,891
1948---	95,620	1,057	94,838	10,322	96,984	10,046	8,554	112,741	89,747	519,909
1949---	80,610	874	68,123	5,354	85,882	7,451	7,988	98,957	90,299	445,538
1950---	88,262	717	60,969	9,088	94,757	7,698	7,943	98,164	86,604	454,202
1951---	101,898	890	54,005	11,418	102,030	7,973	8,525	105,634	76,531	468,904
1952---	103,309	723	37,962	6,912	90,702	6,820	8,073	95,863	68,393	418,757
1953---	112,283	605	27,735	8,226	104,648	6,207	8,362	97,437	61,295	426,798
1954 8/	115,235	427	17,370	894	84,394	4,944	8,153	78,953	52,616	362,986
1955 8/	140,470	461	15,473	2,796	104,580	5,221	8,696	91,856	53,762	423,315

1/ Federal Power Commission. Represents latest available revised figures for bituminous coal and lignite consumed by public-utility power plants in power generation, including a small quantity of coke.

2/ Bureau of Census, U. S. Department of Commerce.

3/ Association of American Railroads. Represents consumption of bituminous coal and lignite by class I railways for all uses, including locomotive, powerhouse, shop, and station fuel. The Interstate Commerce Commission reports that in 1953 consumption for all uses by Class I line-haul railways, plus purchases for class II and class III railways, plus purchases by all switching terminal companies was 29,211,854 tons of bituminous coal and lignite. Similar data from the Interstate Commerce Commission are not yet available for 1954.

4/ Includes a small amount of anthracite.

5/ Estimates based upon reports collected from a selected list of representative manufacturing plants.

6/ Estimates based upon reports collected from a selected list of representative retailers. Includes some coal shipped by truck from mine to final destination.

7/ The total of classes shown approximates total consumption. It is not possible to calculate consumption closely from production, imports, exports and changes in stocks because certain significant items of stocks are not included in year-end stocks. These items are: Stocks on Lake and Tidewater docks, stocks at other intermediate storage piles between mine and consumer, and coal in transit.

8/ Preliminary.

9/ "All other uses." Not available separately.

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The increased use of coal by the public utilities depends upon expanding the use of electric energy and the availability of coal-burning equipment that can supply the necessary heat energy at a cost competitive with that of other fuels. In determining energy costs, the cost of the fuel, handling and storage, reliable uninterrupted operation of equipment, availability of fuel, stack-emission problems, and waste disposal must be considered. Specific research possibilities for improving the technology of solid fuel use for this purpose are shown below.

Improved performance of coal-burning and handling equipment. - Mineral deposits on the convection surfaces of utility steam boilers reduce efficiency, limit capacity, and can result in expensive interruptions in service. An extensive investigation of the causes and prevention of such deposits is needed.

78. Investigate behavior of coal minerals at high temperatures and the effect of trace elements in coal on the formation of boiler deposits.

79. Study mechanical and chemical methods for removing fireside deposits from large boilers.

80. Develop a standard test to determine ash-fouling tendencies of different coals.

81. Investigate the effect of additive compounds to coal on its ash-fouling tendencies and combustion characteristics (see also 103, 110).

Further knowledge is needed for properly evaluating the factors that control and influence the release of heat and its absorption for useful purposes. Specific research possibilities are:

82. Investigate the use of ultrasonic and electromagnetic energy to effect complete combustion.

83. Study combustion of solid fuels under pressure, study of flames, and the effect of steam and flue gas in flame characteristics.

84. Determine the viscosity and thermal conductivity of gases at elevated temperatures. These data are needed for improved design of equipment used in industrial combustion processes.

Although the boilers, burners, and coal-handling equipment used in large utility plants for converting coal to heat energy and electrical energy have been developed to a very high degree of efficiency, areas for improvement remain. Specific research possibilities are:

85. Investigate the mechanisms of simultaneous transfer of heat and mass to assist in designing more efficient boilers and auxiliaries. Develop improved equipment for pulverized-fuel and cyclone-furnace methods of firing (see also 101).

86. Investigate the use of chars as boiler fuel.

Elimination of stack emission. - The emission of sulfur dioxide into the atmosphere from stacks of large powerplants is continuing to be a nuisance of increasing importance. In addition to reducing air pollution by removal of sulfur dioxide, development of a practical process for the removal and recovery of sulfur dioxide from stack gases might reduce the cost of this operation. Specific research possibilities are:

87. Investigate improved means for removing sulfur dioxide from stack gases, among which are scrubbing (1) with an aqueous slurry of manganese oxides with production of concentrated sulfur dioxide, (2) with water followed by conversion of the sulfur dioxide in solution directly into sulfuric acid by catalytic oxidation, and (3) with ammonia to form ammonium bisulfite-sulfite liquor for production of free sulfur and ammonium sulfate; (4) catalytic gas-phase oxidation of sulfur dioxide in the stack for subsequent recovery as sulfuric acid or sulfate; and (5) use of lime slurry (see also 167).

88. Study improved and economic methods for removing solids from flue gas without sacrificing boiler efficiency, including new design of mechanical dust collectors, improved use of electrostatic separation, and high-frequency sound waves (see also 141, 185).

Utilization of waste products. - Study of the conversion of the waste products of coal combustion from a liability to an asset merits attention. The recovery of sulfur products has been discussed earlier in this report. Intensive research may result in the development of new uses for the particulate matter collected from utility plants. Specific research possibilities are:

89. Develop new and expanded uses for fly ash, including use (1) as a pozzolanic material to replace cement in part, (2) as a replacement for I-A slag, (3) as a lightweight aggregate (after sintering), and (4) as a filter in bituminous materials (see also 114).

90. Study improved methods of storing, handling, and transporting fly ash (see also 72, 73, 96).

Economic aspects of coal-heat energy and power transmission. - Many utility plants are currently buying coal on a cost-per-B.t.u. basis. It is known that other factors govern the cost of operation that are not shown in the cost-per-B.t.u. price of coal.

91. Determine the extent to which coal quality influences the overall cost of operation to enable purchasers and producers to determine economic limitations of cleaning coal for thermal power generation (see also 102).

Many private companies, particularly in the primary-metals, chemical-products, and paper-products industries, generate their own electric power. Some of this power is generated using fuels other than coal. Development of new power-generator equipment using coal might increase this market. A specific research possibility is:

92. Study the use of the coal-fired gas turbine as a stationary power plant, particularly for industries that can utilize the energy from the hot exhaust gases.

Motive Power

Railroads. - Before and through World War II railroads were the largest consumer class for bituminous coal, attaining a maximum consumption of 132 million tons in 1944. Because there always had been a strong interdependence between coal and the railroads - the railroads use coal for locomotive and other uses, and coal provides about one-third of the railroads' revenue traffic - the railroads were considered a stable market for coal. After World War II the railroads expanded their use of diesel locomotives, and by 1954 only 17 million tons of coal was consumed for the year, a decline of 115 million tons annually. The decline has not been stopped even yet, since only 15 million tons was consumed by the railroads in 1955. Even though coal-burning gas turbines may replace other fuel-burning locomotives, coal burned by the railroads would not be expected to reach the high tonnage levels formerly consumed.

Ships. - Bituminous coal used as bunker fuel in foreign trade has dropped from nearly 8 million tons in 1926 to less than 1/2 million in 1954 and 1955 owing to the use of oil. Coal used as bunker fuel in the United States coastal trade has dwindled 1.5 million tons in the past 15 years to a mere 135,000 tons. Coal used as vessel fuel on the Great Lakes ranges between 1 and 1-1/2 million tons annually.

Potential Future Energy Demand

Estimated future energy demands for motive power from all sources of energy, in trillion B.t.u. and bituminous-coal equivalents, are indicated below for 5-year periods beginning in 1955 and ending in 1980.

	1955	1960	1965	1970	1975	1980
Trillion B.t.u.	9,365	10,000	10,600	11,300	12,100	13,000
Bituminous coal equivalent (million net tons)	357	382	405	431	462	496

In 1954 - the latest year for which complete data are available - bituminous coal supplied about 5 percent of the total energy used as motive power, the preponderance having been supplied by petroleum products.

Technological Problems and Research Possibilities

Railroads. - In spite of the drastic decline in use of coal by the railroads, development of a practical coal-fired gas-turbine would result in significant savings in fuel costs for the railroads. Specific projects for research to develop coal-burning equipment are:

93. Develop and service-test gas-turbine locomotives powered by coal, using either a closed-cycle gas turbine or producer-gas firing of gas turbines. Present development of open-cycle gas turbines for this use should be continued.

94. Study interchangeability of the coal-fired gas turbine with diesel units on existing diesel locomotives.

Ships

95. Develop improved methods for controlling air pollution produced by coal-burning vessels.

96. Improve storage, bunkering, and handling methods for solid fuels (see also 72, 73, 90).

97. Investigate the potentials for using colloidal fuels.

Other Industrial

Large declines in bituminous-coal consumption have occurred in the broad category of "Other industrial," which is defined to include all industrial consumers other than electric-power utilities, railroads, and coke plants. Where available, however, data are shown separately in table 11 for steel and rolling mills and cement mills. The consumption by this group dropped from 163 million tons in 1943 to 92 million tons in 1954, the lowest for any year on record. In the upswing of 1955, however, coal consumption by the group increased to 106 million tons, still a net drop of 57 million tons from the peak of 1943.

Declining coal consumption in this field has resulted primarily from the increased use of residual fuel oil in industrial fuel markets, of distillate oils in industrial space-heating markets, and of natural gas in both industrial and space-heating markets. These shifts are indicated very simply by the trends in types of fuel-burning equipment sold in recent years. For all kinds of burning equipment on a unit-for-unit basis, in 1948 1.6 units of oil and gas were sold for each solid fuels unit, but in 1953 the ratio was 21 to 1 in favor of oil and gas over solid fuels.

Potential Future Energy Demand

Estimated potential future energy demand for "Other industrial," from all sources of energy, in trillion B.t.u. and bituminous-coal equivalents, are indicated below for 5-year periods beginning in 1955 and ending in 1980.

	1955	1960	1965	1970	1975	1980
Trillion B.t.u.	13,300	14,450	16,050	18,350	21,250	24,750
Bituminous coal equivalent (million net tons)	508	552	613	700	811	945

In 1954, the latest year for which complete data are available, bituminous coal supplied nearly 20 percent of the total energy used by this group of consumers.

Technological Problems and Research Possibilities

Coal-burning equipment for small industrial plants. - The cost advantage that coal enjoys over other fuels in most areas drops in importance as the size of the steam plant decreases. To regain this market, coal-burning equipment must be developed that is competitive in initial cost and provides the automatic operation of other fuels. Specific research possibilities to carry out these objectives are:

98. Develop further a vibrating feeder and grate that can be applied to a new type coal burner to bring about complete automation.

99. Develop further an eccentric-ring stoker with rim feed and center discharge for completely automatic operation (see also 140).

100. Make further combustion studies of thin-bed burning, using the down-jet principle to achieve maximum burning efficiency and smokeless operation.

101. Investigate adaptation of pulverized-coal burners and cyclone furnaces to smaller industrial plants (see also 85).

102. Develop new equipment and conversion parts for existing equipment that will burn low-grade coal efficiently (see also 91).

Stack emission. - Industrial steam plants are nearly always in urban areas, where the prevention of smoke, fly ash, and other pollutants is of concern. Because of the difference in operation, capital investment, and the type and quantity of pollutant emitted, smaller industrial plants often cannot use the pollution-control equipment suitable for large utility plants. Improvements in methods and equipment for small plants to prevent pollution at low costs would assist in regaining this market. Specific research possibilities to carry out this objective are:

103. Study the use of additives to coal for more complete combustion of gaseous and particulate pollutants (see also 81, 110).

104. To reduce the cost of collection equipment, study the possibility of reinjecting into the furnace material collected at the stack.

105. Investigate reasons why the amount of fly ash emitted is not directly related to the ash content of coal.

106. Study the use of water sprays in the stack to reduce air pollution, especially during soot-blowing periods of operation of smaller boilers.

107. Develop devices for instantaneous sampling and determination of the amount of solids in flue gases (see also 109, 201).

108. Investigate the size of coal-ash particles in the unfused and semifused condition.

109. Develop improved instruments, standards, and methods for collecting, measuring, and analyzing dusts, especially in the subsieve range (see also 107, 201).

Coal and ash handling. - The cost and inconvenience of coal and ash handling are deterrents to the use of coal in many small plants, and automatic coal- and ash-handling equipment must be developed for small plants. (For research projects, see 72, 73, 90, and 96.)

Other fundamental aspects of coal combustion. - A thorough understanding of the effects of degree of preparation and addition of chemicals to coal and a study of the behavior of various types of coals under varying conditions of combustion, are needed to permit suitable equipment to be designed for the industrial market. Specific possibilities to carry out this objective are:

110. Investigate the effects of oil and chemical treatment of coal on the combustion, handling characteristics, smoke yield, caking and swelling powers of coal, and ignition and decomposition temperatures (see also 70, 72, 81, 103).

111. Study the effect of water and steam on the chemical reactions of coal mineral matter that lead to clinker formation in fuel beds (see also 78).

112. Study the plastic behavior of coal in an oxidizing atmosphere, particularly with regard to the operation of "crossfeed-type" stokers (see also 140).

Other process uses. - The use of coal as a fuel or as a raw material for a wide variety of other process industries may develop premium markets for coal. Specific research possibilities for the development of such new markets are:

113. Develop equipment to use coal in blast furnaces and for metallurgical heating, such as in open hearth furnaces, soaking pits, heat treating, etc.

114. Develop improved methods for processing clays and shales and waste materials from other industries to produce a superior lightweight aggregate by sintering with very fine coal sizes (1/8 by 0) (see also 89).

115. Study the types and grades of coal suitable for pelletizing low-grade iron ores.

116. Investigate improved coal-fired rotary cement kilns.

117. Study the use of finely divided coal as a filler or pigment for rubber, plastics, etc.

Bituminous coals, particularly those of lower rank, can be solubilized in varying degrees by alkali at elevated temperatures. Some products obtained are important chemicals of commerce and thus make the process attractive as a possible way of producing chemicals from coal directly. A specific research possibility is:

118. Investigate the alkaline hydrolysis of coal for producing chemicals and low-ash carbon. This includes process-variable studies, development of a continuous process, and processes for separating and refining products (see also 207).

Chemicals are being obtained from coal at present primarily by processing the byproducts from the manufacture of coke for the steel industry. Consequently, the quantities available depend upon the demand for steel and represent only a fraction of that required by the chemical industry. The technological problems in the production of raw materials and intermediates for the chemical industry from coal by direct processes thus afford opportunities for research. Specific research possibilities to carry out this objective are:

119. Investigate the oxidation of alkaline slurries of coals for producing carboxylic acids. This includes process-variable studies, development of a continuous process, and processes for separating, refining, and further processing of the products (see also 207).

120. Investigate nitric acid oxidation of coal as a process for the direct production of chemicals from coal (see also 207).

Currently, nitric acid is being made in large quantities by the oxidation of ammonia. The production of nitric acid by the direct oxidation of nitrogen is theoretically possible but requires extremely high temperatures and offers the following possibility for coal research:

121. Develop a coal-fired furnace for use in the direct production of nitric acid from nitrogen.

Reverberatory furnaces. - Reverberatory furnaces are used widely for smelting ores, especially copper and lead ores. Although coal is often used as the fuel, development of improved equipment might increase this market.

122. Study the effects of changes in furnace and equipment design on combustion characteristics of the coal and ascertain which characteristics of coals are most suitable for use in reverberatory furnaces.

Solvent extraction. - Good-coking coals (even in lump form) can be dissolved quickly and almost completely at temperatures above 300° C. (572° F.) in certain coal-tar hydrocarbons and related materials. This property of coal could be used to yield special products or special types of coal for which premium markets might exist. Specific research possibilities are:

123. Investigate the mechanisms of the "solution" of coal in various solvents, including the extent to which this is due to depolymerization, to miscibility in hot oil, to true solution, etc. (see also 131).

124. Investigate uses for ultrafine ashless coal obtained by precipitation, such as compounding rubber and plastics and use as a fuel in diesel-type engines.

125. Investigate products obtained by action of strongly basic amine solvents, such as ethylenediamine, and other solvents on coal for chemical and industrial uses.

126. Investigate the copolymerization of coal extracts with various organic reactants to produce materials for the plastics industry.

127. Study the preparation of coal for special uses by removing virtually all of the ash (see also 131).

128. Investigate methods of removing most of the sulfur from coal (see also 66).

129. Study the production of ultrafine coal particles without mechanical grinding, by precipitating coal from coal solutions.

130. Develop methods for increasing the fluidity of hot-coal solutions to facilitate the removal of mineral impurities (ash, pyrite and fusain), for example, by light hydrogenation, or treatment under moderate pressure with oils capable of transferring some of their hydrogen and to use the hot coal solution as a fuel for pressure gasifiers.

Electrode-carbon manufacture. - There is a large and growing demand for carbon electrodes of various types for use in electric furnaces by metallurgical industries. For example, it is estimated that by 1958 the aluminum industry alone, in the United States and Canada, will require 1.3 million tons of pure calcined coke. At present, petroleum coke and pitch coke are the primary sources of carbon for electrode manufacture. Since it is technically possible to prepare a low-ash coke from coal, research on methods of economically preparing carbons for electrode use might develop this premium market for coal. A specific research possibility is:

131. Study processes for deashing coal (for subsequent coking) that will meet the specifications of the aluminum or other industries for electrode carbon, including dissolving coal in organic solvents to permit removal of ash, extraction of ash with hot acid or alkali solution, selective mining of low-ash coal, and/or intensive cleaning by froth flotation, and volatilization of ash constituents during carbonization or subsequent high-temperature preparation of electrode carbons (see also 10, 123, 127).

Manufacture of specific chemicals. - Coal and coke are used as sources of carbon for chemical reduction and as sources of heat in the manufacture of various sulfides by reduction of the corresponding sulfates. A research possibility for developing this market is:

132. Determine the types and grades of coal best suited to the manufacture of sulfides and sulfites.

Considerable quantities of activated carbon are used to decolorize syrup and other organic materials, remove tastes from water, and recover solvent vapors from effluent air, and in air conditioning. These carbons are manufactured from bituminous coal, lignite, nutshells or fruitpits, etc. Improved processes for manufacture from coal might give coal a larger share of the market. A specific research possibility is:

133. Develop special activated carbon that could be used for separating the constituents of coal gas (for use as chemical raw materials) (see also 165).

The manufacture of certain metal chlorides is based upon first reducing metal oxides in a shaft furnace, using carbon from coal. A research possibility to increase this market is:

134. Determine the suitability of types of coke, coal, and low-temperature chars for the manufacture of chlorides.

Carbon disulfide is currently manufactured in special furnaces from sulfur and wood charcoal. Owing to the high cost and limited availability of suitable wood charcoal, a premium market may exist for low-temperature char made from coal. A specific research possibility is:

135. Investigate the adaptability of coal chars to the manufacture of carbon disulfide.

A number of foreign plants produce sulfuric acid and cement by charging a mixture of anhydrite (natural calcium sulfate), coke, sand, and shale into a rotary kiln and firing with pulverized coal. A specific research possibility is:

136. Investigate the manufacture of sulfuric acid and cement in the United States from anhydrite, coal, sand, and shale.

Calcium carbide is produced in electric furnaces from a mixture of lime and coke, anthracite or charcoal. It is the source of acetylene, an organic raw material of growing importance, and has many uses. A specific research possibility is:

137. Investigate the substitution of reactive char made from coal for other carbon sources in the manufacture of calcium carbide, and as fuel for calcining the lime.

The technological problem and the research opportunities pertaining to the conversion of coal into (1) liquid and gaseous products by reactions with hydrogen and (2) into hydrogen-carbon monoxide mixtures are treated separately elsewhere in this report.

Residential and Commercial Heating

The increasing availability of fuel oil, from both domestic and foreign sources, and of natural gas, with their strong appeals as to convenience and cleanliness, have been taking an increasingly heavy toll from coal's residential, space-heating, and commercial markets.

Whereas coal deliveries to retail dealers reached a peak of 125 million tons in 1944, they dropped to 53 million tons in 1954, a market decline of 72 million tons (table 11). In 1955 retail deliveries increased approximately 1 million tons over 1954.

Potential Future Energy Demand

Estimated future energy demand for residential and commercial uses from all sources of energy, in trillion B.t.u. and bituminous-coal equivalents, are indicated below for 5-year periods beginning in 1955 and ending in 1980:

	1955	1960	1965	1970	1975	1980
Trillion B.t.u.	8,265	9,600	10,700	11,900	13,300	14,900
Bituminous coal equivalents (million net tons)	316	366	405	454	508	569

In 1954, the latest year for which complete data are available, bituminous coal supplied nearly 17 percent of the total energy used for these purposes.

Technological Problems and Research Possibilities

Combustion equipment. - Automatic coal-burning equipment is of paramount importance for coal to retain the maximum amount of the residential and commercial market. The most popular coal burner for this market is the underfeed stoker, but marketability is limited by need for attention, ash and clinker removal, and restrictions on usable coal sizes and types. Specific research possibilities to solve these problems and thus retain the maximum market for coal are:

138. Develop packaged-type coal-burning equipment in which the stoker, heat exchanger, controls, and automatic coal- and ash-handling equipment are easily and cheaply installed.

139. Develop underfeed stokers of improved design with automatic ignition and ash removal and capable of burning a wide range of coals.

140. Further testing of crossfeed-type stokers to develop a completely automatic small coal burner (see also 99, 112).

141. Develop low-draft-loss dust-collection equipment for use with coal burners operating on natural draft (see also 88).

142. Develop improved methods of coal pulverization and delivery for use in pulverized-coal burners in small plants (see also 59).

143. Develop equipment for warm-air industrial space heating with capacities exceeding 150,000 B.t.u. per hour.

Handling and storage. - Coal for residential and commercial use is rehandled and stored at retail-dealer yards or at plant sites. This double handling of coal increases the problem of degradation and increases costs to consumers. Development of suitable small-scale equipment to improve coal-handling and storage problems for this use would reduce these costs. Specific research possibilities are:

144. Improve methods of storing and handling coal in retail-dealer yards to reduce degradation, segregation, and dust (see also 63, 72, 73, 75).

145. Improve home- and plant-bin design to provide maximum live storage with existing conveyor equipment.

146. Study the use of pneumatic coal- and ash-handling systems for offtrack customers (see also 16, 71).

New market areas. - A new market for coal-burning equipment exists in the expanding use of heat for farm use. This market has had negligible attention. Specific research possibilities are:

147. Develop improved coal-fired heating equipment to replace wood-burning units for curing tobacco.

148. Develop coal-fired central-heat systems for use in broiler-chicken barns.

149. Develop coal-fired equipment for forced warm-air drying of forage crops.

Coke and Coal Chemicals

The consumption of bituminous coal in manufacturing oven and beehive coke has increased about 44 percent during the 30-year period, 1925-55, an average yearly gain of approximately 1.5 percent. The yearly increase has not been uniform, however, as peaks and valleys have paralleled those for iron and steel production. Table 12 shows the actual consumption for each of the 5-year periods in the period indicated above.

TABLE 12. - Consumption of bituminous coal in the manufacture of oven and beehive coke for 5-year periods, 1925-54, in net tons

Period	Total	Yearly average
1925-29	395,821,584	79,164,317
1930-34	236,455,804	47,291,161
1935-39	301,098,250	60,219,650
1940-44	482,941,453	96,588,291
1945-49	481,978,340	96,395,668
1950-54	512,193,475	102,438,695

Potential Future Energy Demand

With virtual disappearance in the last 20 years of the use of coke for residential heating and production of gas for residential consumers, the future demand for coking coal will be determined largely by the rate of growth of the iron and steel industry and technological activity within this industry. Changing iron-ore supplies (rich foreign ore) and improved technology in iron-ore beneficiation (taconite concentrates and sintered ores) indicate that fuel efficiency in blast furnaces can improve markedly in future, which, in turn, will influence coking-coal requirements. Estimated future coking-coal requirements in this report are predicated on population growth estimated by the Bureau of the Census, a small rise per year in steelmaking capacity per capita, and a slight decline in the coking coal - steel ratio. Using this procedure, potential demands for coking coal between the years 1955 and 1980 are estimated to be as follows:

	1955	1960	1965	1970	1975	1980
Trillion B.t.u.	2,805	3,300	3,600	3,900	4,300	4,700
Bituminous coal equivalents (million net tons)	107	126	137	149	164	180

These estimates are based on the anticipated need for coal for both steel and other coking-coal uses.

Bituminous coal supplies virtually all the coal used in coke ovens; only a very small amount is Pennsylvania anthracite.

Technological Problems and Research Possibilities

The survey of current coal research showed a reported annual expenditure of $5,435,400, with 273 professional men employed on all phases of coal carbonization (including the initial processing of coal chemicals at the originating plant). Complete figures would be somewhat higher than those reported in the survey. This classification represents the largest research expenditure related to coal, and is 31.3 percent of the total amount reported for coal research.

Availability and quality of coals for coking. - The present practice of cokemaking in high-temperature slot-type ovens has been developed primarily on an empirical basis, using the best coals commercially available in each area. Owing to rapid depletion of the more suitable coking coals, to the increased cost of producing coke, to changing ore supplies, and to development of new technology in iron-ore beneficiation and processing, a number of opportunities for carbonization research exist. Specific research possibilities are:

150. Determine the behavior of the petrographic constituents of coals during cleaning and coking, and apply this knowledge to improve the coking qualities of coals through selective preparation and blending. The study would include the use of controlled amounts of deduster dust, washery fines, and other waste material to achieve high-quality, more uniform coke (see also 55).

151. Develop equipment to control and record automatically the moisture content of crushed coal being charged into coke ovens (see also 62, 201).

152. Determine possible advantages of crushing separately the high- and low-volatile components of coke-oven blends to control the size consist of each component.

153. Investigate the effect of blending low-temperature chars on the carbonizing properties of coals.

Pretreatment of coals for coking. - Only a small proportion of United States coal reserves has ideal properties for coke manufacture when carbonized alone. With depletion of these coals, it will become necessary to pretreat available coals to maintain coke quality, to meet specifications for new metallurgical processes, and to control costs. Specific research possibilities are:

154. Investigate methods of pretreating weakly coking or noncoking coals to make them suitable for manufacturing metallurgical coke or other large-size carbon agglomerates, either alone or in blends with strongly coking coals.

155. Investigate the behavior of coals during carbonization with reference to the effect of the rank and type of coal and operating variables on the carbonizing process.

156. Develop full-size test ovens or pilot-scale test ovens and procedures that will give reliable results for predicting the behavior of coals or coal mixtures in commercial coke ovens.

157. Study effect of pretreating coal, below the plastic temperature, on carbonizing characteristics.

158. Determine the effect of additives to the coal charge on the yields, properties, and value of the coke, tar, gas, etc. (see also 163, 174).

159. Investigate the coking of special mixtures, such as mixtures of coal and iron ore, to produce "Ferrocoke" for blast furnaces.

High-temperature carbonizing equipment and conditions. - There has been continuous engineering refinement in the technology of coke-oven design, materials of construction, operation, and maintenance. Nevertheless, with increased costs of building and operating coke ovens, there is strong need for lower cost and higher throughput equipment. Specific research possibilities are:

160. Study means of accelerating the rate of heat transfer in conventional coke ovens, using new materials of construction, new design, and faster coking processes.

161. Develop a continuous process for manufacturing coke, including the use of horizontal chain-grate-type ovens.

162. Study methods for eliminating sulfur during carbonization and of minimizing the effects of sulfur in blast-furnace operation (see also 173).

163. Investigate the use of chemical additives to coal charges to produce less pitch and a higher yield of the more valuable low-molecular-weight compounds (see also 158, 174).

164. Investigate the free radicals present during the volatilization of coal and devise means for controlling their reactions to improve the products (see also 166).

Upgrading primary coke-oven products. - An important cost factor in determining the price of coke is the credit received from coal chemicals. Important possibilities exist for increasing the value and marketability of these primary products at the coke plant. (The scope of this report does not include processing elsewhere, - for example, at tar refineries or chemical plants.) Specific research possibilities are:

165. Develop better methods for separating the constituents of coke-oven gas (hydrogen, methane, ethane, ethylene, etc.) for the production of chemicals (see also 133, 180).

166. Study the upgrading of primary coal products in the nascent state to obtain products that have a better commercial market (see also 164).

167. Study the use of coke-plant ammonia to control sulfur dioxide emission from powerplant stack gases, with production of ammonium sulfate (and concentrated SO_2 if desired) (see also 87).

168. Study the upgrading of coal tar at the coke plant by converting high-molecular-weight constituents into more valuable chemicals, through thermal vapor-phase cracking of tars or tar fractions, hydrogenation refining, and dealkylation of tars or tar fractions to produce larger yields of the simpler aromatic hydrocarbons (see also 179).

Low-temperature carbonization. - The low-temperature carbonization of coal has, in theory, many attractive economic potentialities. The separation of the potentially valuable tars and chemicals from the coal before use as a fuel appears to be an attractive method for using this natural resource. The development of a cheap process for carrying out this separation and the development of suitable markets for the tar should reduce the cost of the char that can be used for the production of electricity. Reducing this cost would improve the competitive position of coal for use by electric utilities. Development of premium uses for the char might also develop new markets for coal. Specific research possibilities to achieve these objectives are:

169. Conduct research on physical conditions and chemical reactions during low-temperature carbonization to develop improved processes.

170. Develop reliable small-scale test methods for predicting the performance of any coal during low-temperature carbonization.

171. Develop better methods for separating solid particles (of char, ash, or coal) from tar in the vapor phase.

172. Develop better methods for safe handling and transporting of hot char to the point of consumption without loss of heat.

173. Develop methods for increased elimination of sulfur from the char during low-temperature carbonization (see also 162).

174. Develop improved methods for cracking primary low-temperature tar during the carbonizing process, to yield more valuable tar products (see also 158, 163).

175. Study the characteristics of products from low-temperature carbonization to improve the design of low-temperature carbonizing plants and accessory equipment.

176. Investigate the fundamental physical and chemical differences between chars and cokes and the effect of operating variables upon the physical and chemical properties (see also 205).

Special or upgraded products from low-temperature carbonization

177. Determine the optimum operating conditions for producing chars for blending with coking coals for high-temperature coking, carbons for use in low-shaft furnaces, reactive carbons for reducing agents in various metallurgical and chemical processes and carbons for electrode manufacture.

178. Study the production of agglomerated or nodulized products from mixtures of coking coal, iron ore, etc., that will be suitable for smelting iron ores to iron or crude steel by various processes.

179. Make a comprehensive investigation of the nature and composition of low-temperature tars and conversion of these tars into more valuable low-molecular-weight materials (see also 168).

180. Develop better methods for separating the constituents of low-temperature-carbonization gas (see also 165).

Gasification and Uses of Synthesis Gas

The huge potential market for producer gas, water gas, and high-B.t.u. gas has brought about increased interest in direct gasification of coal, especially since petroleum and natural gas are becoming more expensive and less abundant.

Coal may be gasified with air and steam to yield producer gas, a mixture consisting of nitrogen, carbon monoxide, and hydrogen. Its low heat value makes producer gas as such suitable only for industrial use at or near the plant, although it may be piped short distances when used as a diluent of pipeline gas. It may be particularly useful in certain processes for making synthesis gas or even in a modification of the Fischer-Tropsch process. However, a more versatile product is obtained by reacting coal with steam and oxygen to avoid dilution with nitrogen. The water gas resulting from this process contains roughly equal amounts of carbon monoxide and hydrogen. This gas (after further treatment) is now used in the manufacture of ammonia and would constitute the biggest available source of hydrogen for hydrogenating coal and its products (see Coal Hydrogenation section). It may also be used to generate electricity in the so-called fuel cell. A wide range of mixtures of carbon monoxide and hydrogen can be prepared from water gas.

Mixtures of carbon monoxide and hydrogen are the raw materials for making methanol, higher alcohols, and a large variety of other organic chemicals ranging from pipeline gas to wax. Some of the methods for making these materials are in commercial use - the oxo and alcohol syntheses; another, used in foreign countries and under intensive study here, is the Fischer-Tropsch process; and still others have received relatively little attention until recently, such as the isosynthesis and the methanation reaction. Except for the oxo reaction, in which an organic compound is reacted with synthesis gas, all of these processes involve reacting carbon monoxide with hydrogen. Differences in products are determined by the ratio of these gases, the nature of the catalyst, and the operating conditions.

Potential Future Energy Demand

According to published data for 1955, about 92 percent of the commercial ammonia was made in synthetic ammonia plants and less than 8 percent from coke. However, several large synthetics plants used coal or coke in their ammonia production in 1955, but it appears that even some of them will discontinue using coke in the near future.

The growth in ammonia production over the past 20 years has been very large, and the predictions for additional growth are also optimistic. Synthesis gas from coal for the production of ammonia can be obtained (1) by direct gasification of coal, (2) by removing hydrogen from coke-oven gas, and (3) by re-forming the total gas stream from the coke plant. Processes have been developed for using hydrogen from coke-oven gas, and if all of the hydrogen from coke-oven gas were utilized, over 6,000,000 tons of ammonia per year could be produced (present ammonia production is about 3,000,000 tons per year). The availability of synthesis gas by direct gasification of coal would not be limited by being a byproduct from some other operation and might be cheaper than hydrogen produced in other ways.

No other significant market exists at present for synthesis gas from coal, but the production of electricity via fuel cells and of organic chemicals by means of one or more of the processes defined above are distinct possibilities. The largest potential market, by far, appears to be that for synthetic liquid and gaseous fuels. The time when coal will first be used for these purposes and the rate of expansion of such new industries are subject to such factors as the world political situation; the price of coal, supply of power, equipment, and manpower; and the price and supply of petroleum and natural gas. But even apart from concern about assured supplies of such fuels at any cost from a strategic point of view, the opinion has been expressed repeatedly that we shall be forced into coal-to-oil production within 15 to 20 years, simply because the supply of other liquid and gaseous fuels will not take care of demand. Although coal is the biggest potential source of synthetic fluid fuels, it is not the only one; tar sands and bituminous sands and oil shale can be processed to yield similar products and at lower cost. Thus, the role that coal will play in supplementing fluid fuels now available will depend to a great extent on drastically reduced processing costs. The cost of gasification represents

70 to 80 percent of the cost of the final product for the Fischer-Tropsch and methanation processes and a smaller but significant percentage of the cost of the final product from the coal-hydrogenation process.

Indications are that high-B.t.u. gas for pipelines (essentially methane) will be needed first. Not only have wellhead prices advanced, but the cost of long-distance transportation raises the price of natural gas greatly for areas remote from the source. As natural-gas prices rise and the cost of conversion of coal to methane is lowered sufficiently, the time will be advanced when high-B.t.u. gas from coal will be produced economically in the United States.

Cost considerations are not as important for the production of chemicals that demand premium prices. Thus, industry is already devoting considerable effort toward producing aromatic hydrocarbons, phenols, tar bases, alcohols, aldehydes, and ketones from coal.

The future demand indicated in table 4 did not differentiate between the forms in which the energy would be available. The long-range forecast for decreasing domestic supplies of petroleum and natural gas and the convenience factor in using these fuels strongly indicate that a portion of the energy supplied by coal in future will come from its conversion to synthetic liquid and gaseous fuels, even at premium prices. The magnitude of the potential demand for coal by such processes is enormous. The coal required to replace only 5 percent of the (1952) natural-gas and liquid-petroleum demands with synthetic products would be over 100,000,000 tons per year. Intensive research is required to reduce the costs of gaseous and liquid fuels from coal to shorten the time at which coal will become a competitive raw material.

Technological Problems and Research Possibilities

Production of synthesis gas. - Several methods have been developed for gasifying coal, purifying the gas, and changing the composition of the gas to suit further processing. However, not all coals are amenable to the gasification processes now available. Difficulties may develop because of caking, slacking, and clinkering, for example. To overcome these, pulverized coal may be gasified in an entrained bed. Satisfactory ways must still be found for feeding coal to the reactor, especially for pressure gasification. Alternative methods of producing oxygen or gasification without the use of oxygen may be needed to make synthesis gas economical for producing a bulk commodity like fluid fuel.

181. Study mechanism and rate of gasification.

182. Investigate feeding and gasification methods for powdered coal, especially under pressure.

183. Study gasification processes that do not use oxygen.

184. Study gasification with nuclear energy as a source of heat.

185. Investigate cleaning of raw synthesis gas, including removal of gaseous, liquid, and solid impurities (see also 88).

186. Study process variables for oxygen-gasification processes in fixed, entrained, and fluidized beds.

Utilization of synthesis gas. - The fuel cell, intended to convert coal or a primary reaction product of coal directly to electricity, has not become a commercial reality as yet. Bituminous coal does not appear to be usable as such, but water gas does offer practical opportunities, one of the main deterrents being its high cost. A specific research possibility is:

187. Investigate producing electricity by the indirect fuel cell, using gases.

Common features of the reactions of synthesis gas to produce chemicals and fuels are that the processes occur in the presence of catalysts and that the useful products may range from gas to wax. A particularly difficult problem is removing the heat of reaction from the system as rapidly as it is produced to prevent damage to the catalyst. Methods for doing this have been developed for the Fischer-Tropsch and methanation processes; the effect is accomplished at the cost of pumping gases or liquids through the reaction systems, so that the system must be designed to offer minimum flow resistance to keep the cost of pumping low. Proper choice and conditioning of catalysts, as well as use of optimum processing conditions, will aid in getting maximum amounts of the desired products and minimum amounts of undesired ones. For example, the Fischer-Tropsch reaction can be used to produce mainly higher alcohols, or mainly gasoline, or mainly wax; in each instance as little as possible of the other products should be produced. Specific research possibilities are:

188. Study the structure of catalysts and the mechanism of catalytic reactions, including sulfur poisoning of Fischer-Tropsch catalyst, methods of reactivation of poisoned catalysts, and the development of sulfur resistant catalysts.

189. Develop new types of catalysts (powder and fiber metallurgy, alloy and skeletal catalysts) that are active and durable.

190. Determine operating conditions most suitable for desired products, including selection of the most suitable catalysts.

191. Develop reaction systems suitable for large-scale use (adequate cooling by gases and/or liquids), including systems for methanation.

192. Study methods for characterizing, separating, and upgrading products (see also 198).

193. Study methods of combining processes to produce maximum amounts of desired products with the cheapest available gases (see also 197).

Coal Hydrogenation

The earliest method used commercially for converting coal to liquid fuels was coal hydrogenation. In this process coal is combined directly with hydrogen at high pressures and temperatures, usually in the presence of a catalyst. The Germans erected their coal-hydrogenation plants when methods were not yet available for converting the products from the Fischer-Tropsch synthesis to high-octane gasoline. Today, both processes can be made to yield premium fuels, despite the fact that the products from these are chemically different.

What has been said in the previous section on gasification about potential markets applies here, too. At present, only the production of high-priced chemicals by direct hydrogenation of coal appears economically feasible.

Technological Problems and Research Possibilities

The problems peculiar to coal hydrogenation, apart from gasification, are principally the sluggishness of the reaction at low pressures and separation of products, particularly removal of unreacted coal and ash from the heavy-oil fraction. Furthermore, the effects of operating variables upon rates of reaction and relative abundance of products are known only over a narrow range. Expansion of the range of information is needed for designing "tailor-made" processes, for example, to produce primarily high-B.t.u. gas from coal and hydrogen. In addition, coal hydrogenation requires special and expensive equipment, because pressures of 6,000 to 10,000 p.s.i. are needed for exhaustive hydrogenation.

A number of possible alternatives to the conventional process have been considered, such as hydrogenation of dry coal (instead of coal-oil pastes), low-pressure hydrogenation followed by coking of the heavy oil, one-step hydrogenation at high temperatures, and hydrogenation over a range of temperatures in a single vessel. Results available thus far indicate no really significant reductions in cost compared with the conventional process for exhaustive conversion of coal to liquid fuel. Specific research possibilities are:

194. Make a systematic study of effect of process variables on rates of reaction and product distribution.

195. Investigate the mode of action of various catalysts, the chemical changes produced in catalyst during hydrogenation, and the development of improved catalysts.

196. Investigate methods for reducing the high pressures required in conventional process, by use of catalysts, inhibitors, and temperature-time relationships (see also 200).

197. Study the combination of hydrogenation with other processes, for example, carbonization or solvation (see also 193).

198. Study methods of characterizing, separating, and upgrading products (see also 192).

199. Develop improved equipment for removing solid residue from heavy oils.

200. Study processes for coal hydrogenation at temperatures higher than usual, including production of pipeline gas (see also 196).

PHYSICAL AND CHEMICAL PROPERTIES OF COAL

Despite progress in coal research, we are still far from knowing and utilizing coal to the fullest extent. To be sure, empirical methods are available for analyzing and classifying coal in such a way that buyers and sellers can agree upon the quality of coal being traded. But even in routine analysis, significant advances could be made in speed, accuracy, and economy by adapting new methods and equipment to coal requirements. Specific research possibilities are:

Technological Problems and Research Possibilities

201. Introduce simplification and automation of analysis procedures, adaptation of new analytical and research tools, and development of continuous analytical equipment for process control (see also 62, 151).

202. Apply statistical methods to analysis and process control.

203. Standardize procedures and terminology.

Tremendous gaps exist in our knowledge of coal, its origin, physical structure, and chemical behavior. These voids are not serious as long as coal is used largely as a fuel; but the need for more thorough understandings of coal and its products becomes more pressing as other uses of coal gain importance. For example, (1) low-temperature carbonization is likely to become an important industry, once we know the constituents and potential uses of the tar; (2) larger quantities of chemicals and more valuable ones could probably be obtained from coal at low cost if we knew its basic building blocks; (3) present methods of preparing and processing coal can become better adapted to needs and thus more economical when we learn precisely how coal behaves when subjected to mechanical, chemical, and thermal forces; and (4) as a result of new knowledge acquired about coal, new processes may be found for utilizing its full value. Gentler treatment under milder conditions probably will result in less waste, more valuable products, and less costly equipment and processing.

To reach these goals, we must first learn more about coal's geologic and biologic origins; about the factors (such as time, temperature, pressure, and bacteria) that formed and changed coal; about its petrographic and chemical composition and the origin and nature of the associated minerals; about the physical structure and chemical structure of coal; and about the nature of weak spots or reactive sites in coal that respond to chemical or other attack.

Industrial experience has shown that most modern improvements in equipment design and in processing techniques are based on scientific advances that had been developed many years earlier. Conversely, insufficient effort in research makes itself felt years later by the lack of data and ideas on which to base new advances.

The experience and information gained from such studies of coal will result in more rational approaches and entirely new avenues to coal processing; they are absolutely essential as bases for the other research possibilities discussed in this report.

Research possibilities closely allied to resources, production, distribution, and coal markets are listed under the pertinent headings. This section concerns problems common to all of them or more fundamental in nature. Specific research possibilities are:

204. Study distribution and nature of plant residues, moisture, and minerals in coal (see also 1).

205. Study the physical properties of coal, such as surface and pore structure, density, molecular weight, hardness, plasticity, absorption of radiation, and electrical and magnetic behavior (see also 176).

206. Study the arrangement of coal carbon in ordered arrays, identify molecular groups and fragments, and determine the type and strength of chemical bonds.

207. Study the reaction of coal with acids, alkalies, oxidants, reductants, solvents, and living organisms (bacteria, fungi, molds) (see also 118, 119, 120).

208. Determine the products obtained upon heating coal in various atmospheres, at different pressures, and with catalysts (see also 155, 158).

209. Investigate the analogies between reactions of coal and those of coal models and pure chemicals.

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